METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

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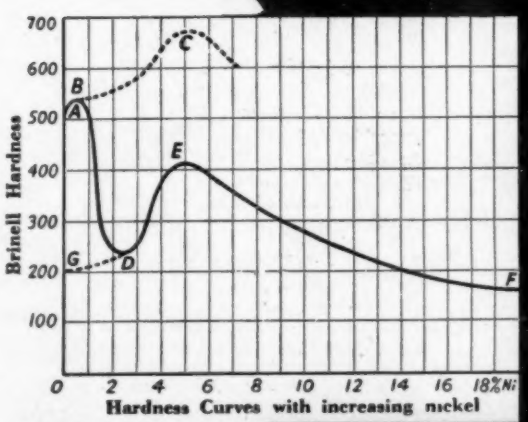

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METALLURGIA

THE BRITISH JOURNAL OF METALS.

INCORPORATING "THE METALLURGICAL ENGINEER."

DECEMBER, 1944 VOL. XXXI. No. 182

Britain's War Achievements

A GREAT change has been effected in the fortunes of the Allied Nations since the beginning of this year; the second front, which involved preparation over a long period, was successfully opened, and in a relatively short time Belgium, France and Holland were substantially released from their thraldom. As a prelude to this remarkable undertaking the major part of the Italian forces had surrendered unconditionally and unremitting pressure has since been brought to bear on that part of Italy which, with German aid, continues to resist the Allied Forces' advance. Greece, too, has been liberated from the German yoke. The year has seen tremendous advances made on several fronts by the Soviet Union, whose Forces have had a very great effect in bringing about the favourable position now held by the Allied Forces in Europe.

MAY we take this opportunity of extending to all readers Sincere Greetings and Best Wishes for a Happy Christmastide; may the New Year bring the Victory for which we are all striving.

Thus, in the fifth year of the war, the results of steady and persistent work, hard fighting and planning are gradually bringing about a climax which will eventually mean the subjugation of Germany. How long victory will be delayed it is not wise even to hazard a guess, but the position of the Allied Forces is now so favourable that Germany can have little or no hope even in the possibility of effecting a stalemate. Her surrender appears to be a foregone conclusion, and yet a long time might elapse before she realises that further sacrifice on her part will not affect the ultimate result.

In this year of tremendous happenings Britain has played, and is playing, her part in speeding on victory. Not only did she contribute the major part of the armada which carried the invading Forces, but from the initial landings her troops have fought with intensity and have shown valour not excelled by any other Forces engaged. That endurance exhibited during the critical year of 1940 has not diminished, indeed Britain has become the arsenal for the Western attack on Germany and, as we stated in our editorial last December, the majority of those in daily contact with the war have been more concerned with duties directed to the speeding of victory; it has been difficult, therefore, to take a detached view of what Britain has, so far, achieved towards this final result. Until recently, the tendency has been to underrate this country's contributions in the great change effected. The natural characteristic of the British to praise the efforts of others and to look upon their own sacrifice and achievements as more or less normal under the circumstances, is probably the major cause, but British propaganda has not helped much to give the proper perspective to Britain's contributions. The recent Government White Paper, however, tells the world the remarkable story of her unparalleled war achievement.

This document, with the prosaic title "Statistics Relating to the War Effort of the United Kingdom," by means of figures and with cold and formal language, tells a story of great human achievement and endeavour in five years of war. During this period Britain has produced more than 102,000 aeroplanes, 25,000 tanks, over 35,000 guns, built 5,700 ships, and saved upwards of £4,800,000,000. Out of 13,000,000 houses in the United Kingdom at the outbreak of war, 4,500,000 have been damaged by enemy action. Of these 202,000 have been totally destroyed or damaged beyond repair. Up to August of this year 57,298 civilians had been killed and 78,818 seriously injured by enemy action against this country. These figures tell the story of the endurance of a people who, against a background of complete blackout, under bomb attacks, with homes shattered and broken, forged the weapons to carry on the war victoriously, saved immense sums to contribute to further efforts, and endured all the adversities of a nation in the front of the greatest war in history.

The scale of mobilisation achieved has been far greater than in the last war. The number of men and women in the Services or industry reached its highest level towards the end of 1943, by which time labour was fully mobilised. By the middle of 1944 four and a half million men were in the armed Forces, compared with 477,000 at the beginning of the war. Including killed, missing and prisoner, or released on medical or other grounds, the total number of men who have served or are serving in the Forces is over five and a half millions. Fifty-seven per cent. of all men between 18 and 40 have been called to the Forces. From the total of 11,200,000 men remaining in civil life in the middle of 1944, one and three-quarter millions were in the Home Guard and a further one and a quarter millions in part-time Civil Defence. Most of the remainder were on fireguard duties.

The high degree of mobilisation has been largely due to the contribution by women. It is noteworthy, for instance, that at the middle of 1944, out of sixteen million women, aged between 14 and 50, 7,100,000 were in the auxiliary Services, whole-time Civil Defence, or industry, an increase of over two and a quarter millions since the beginning of the war, or—counting each woman working part-time separately—an increase of nearly two and three-quarter millions.

Although it has only been possible to present some figures from the White Paper in a very brief form, they tell the story of the intensity of our present concentration upon specialised war efforts—how the whole nation

has been geared up for an all-out effort in the armed Forces, in Civil Defence, in the factory, on the land, and in the home. One tremendous fact stands out clearly—per head of the population, the war effort of Great Britain is greater than that of any other belligerent. The White Paper gives many examples of the single-minded devotion of a people who have put all their energies and resources into the common cause.

Building Uses for Cast Iron

WE are so accustomed to associate cast iron with engineering that its application as a material for building and domestic purposes is frequently overlooked, yet of the 2½ million tons of iron castings produced annually in the foundries of Great Britain about one-third comprise castings for building and domestic uses. Ordinary builders and domestic castings represent about one-sixth, the balance being pipes and civil engineering castings, etc. It is probable that for some years after the war the demand for builders and civil engineering work may approach one-half of the total production, because this work has an early priority in post-war reconstruction.

The Council of the British Cast Iron Research Association, since the inception of the Association, have appreciated the importance of this section of iron-founding, and, in co-operation with the British Iron-founders' Association, established a Building Uses Department in July of this year. This department was opened with Mr. D. L. Bridgwater, F.R.I.B.A., as consulting architect, in charge. The object of the department is to provide an impartial source of information for architects, quantity surveyors, industrial designers, builders and others with respect to the building uses and applications of cast iron.

On various occasions, including the members' annual visit on June 28 and the visit to the Scottish Laboratories of the Association on August 16, a small exhibit relating to the Building Uses Department has been prepared. A more ambitious project of this kind has now been arranged, which is to form a basis for a permanent exhibition to be shown at various centres. The first of these is at Alvechurch, near Birmingham, the headquarters of the British Cast Iron Research Association, which the writer has been privileged to view.

Well over 100 examples of iron castings are exhibited, some of which are photographically displayed. These not only include modern applications, but utility and decorative applications that were more common in earlier days. For instance, the first bridge made in cast iron is illustrated. This was erected in 1779 over the Severn, at the place now known as Ironbridge. This bridge still stands, and is scheduled as a public monument by the Office of Works. Although apparently never painted or surface finished in any way, it shows remarkably little signs of wear and tear after over 160 years' use. That cast iron is both robust and durable is not always appreciated, but there is plenty of evidence to substantiate the claims for this material. Many readers will remember that the Crystal Palace, designed by Sir Joseph Paxton for the 1851 Exhibition, was a complete glass and cast iron structure. The familiar post-office pillar-boxes and telephone kiosks are also of cast iron; many of the former still bearing the monogram of Queen Victoria, but there are many instances of iron castings wearing for centuries, and in this respect mention might be made of the original cast-iron pipes supplying water to the fountains at Versailles, which are still in use.

Some of the principal building applications of cast iron include rainwater, hot water and steam-pipes and gutters; sanitary castings; gas, water, sewage pipes and fittings; baths, stoves, grates, cookers for gas, electricity and solid fuel; tanks, basins, sinks; parts for domestic appliances, such as refrigerators, irons, etc.; domestic boilers, furnace pans, coppers, radiators and radiator fittings; hollow-ware, bedsteads, piano frames. Builders' furniture and its ironmongery—locks, keys, hinges, etc. Road and traffic furniture, including signs, name-plates, milestones, bollards, road sets, curbs, lamp and electric standards, telephone boxes, pillar-boxes, police and first-aid boxes, shelters, gates, fences, parapets, railings; municipal castings, such as manhole covers, gratings, public works castings for piers, promenades. Tunnel segments and many decorative spiral staircases are of cast iron.

Repairs to Bomb-damaged Homes

THE slow rate of progress in making blitzed homes habitable is causing much concern. The recent debate on Housing in the House of Commons indicated that the position was far from being satisfactory, and the views expressed undoubtedly reflected opinions throughout the country. The fact that those who have suffered bomb damage to their homes are bearing their misfortune so admirably should inspire the Government with the need for urgency in the task of making damaged homes weather-proof.

It has been stated that shortage of material, particularly wall board, and shortage of skilled building workers are responsible for the delay. The difficulty experienced in obtaining adequate supplies of wall boarding of the type generally used is understandable, but is this the only material capable of being used to effect temporary repairs? It would seem that by using a bigger range of materials that difficulty could be reduced. Galvanised sheets could also be used, as well as several other metals in sheet form. Here again shortages may be just as acute, but if several kinds were made available homes could be made weather-proof quickly.

Of the metal sheets admirable for this work, those in aluminium would be most effective. These sheets are light, non-corrosive and require no painting; they are easily nailed or screwed down to make a weather-proof roof, or for ceilings, wall panels, aprons between the upper and lower bay windows, and can be used to replace lead or zinc flashings. Aluminium sheet is easily handled and transported, and no special skill is required in using it to effect emergency repairs. Unlike other sheet metals, which could be used, there is a large stock of aluminium in the country, much of which is in sheet form and could be supplied for immediate use. Even if the available stock of aluminium sheets were exhausted, the rolling mills could quickly meet all possible needs.

Deformation of Metals

By Professor H. W. Swift, M.A., D.Sc.(Eng.), M.I.Mech.E.

(The University of Sheffield).

The need for some knowledge of metallurgy on the part of the engineer has greatly increased in recent years owing to the growing diversity and complexity of the metals and alloys available. On the other hand, it is not less important that the metallurgist should familiarise himself with the problems of the engineer, especially with regard to deformation of metals. Although fundamentally associated with physical metallurgy, this subject is of great importance in applied mechanics, and to certain of its problems the engineer can and does make useful contributions through his knowledge of the mechanics of stress and strain. In this article, which is based upon a recent lecture by the author to a joint meeting of the Manchester Metallurgical Society with the Iron and Steel Institute and the Institute of Metals, is put forward an engineer's assessment of the problems involved in this subject and of the contributions which can be made to it by the application of mechanical principles.

As an engineer, the author has some diffidence in offering to metallurgists any views on a subject whose problems are fundamentally those of physical metallurgy, and his only justification is the hope that to certain of these problems the engineer may be able to make a useful contribution through his knowledge of the mechanics of stress and strain. The author will therefore not presume to approach the subject of plastic flow from any point of view involving metallurgical experience, still less to dogmatise on metallurgical theories, but will try to put forward an engineer's assessment of the problems involved in this subject and of the contributions which can be made to it by the application of mechanical principles. This treatment may help to draw attention to those phenomena which require essentially metallurgical explanation and to certain general conditions which need to be fulfilled by any metallurgical theories of slip or strain-hardening.

In order to obtain a proper conception of plastic deformation it is necessary :—

1. To define the range within which the conditions of plastic flow operate.
2. To ascertain the laws of plastic flow within that range.

The effective plastic range is limited at one end by the conditions of elastic breakdown and at the other by the conditions of ultimate rupture.

Inception of Plastic Flow

The conditions for the inception of plastic flow have been, and to some extent are still, a matter of controversy, and experimental evidence is not entirely conclusive, because under the combinations of stress convenient for experiment the predictions of the more eligible hypotheses do not differ greatly from one another.

The three hypotheses which survive direct experimental test and remain on the "short list" are those which regard the limiting factor as (*a*) maximum shear stress ; (*b*) shear resilience ; and (*c*) total resilience. Although there is some experimental evidence in support of (*a*) in the important but non-representative case of annealed mild steel, on the whole, and certainly for other metals the evidence is in favour of one or other of the energy hypotheses. It is well established, of course, that the yielding of single crystals occurs at a fixed value of the shear stress along certain preferred planes, but this is not in general the same as the maximum shear stress, and the yield strength of the crystal varies widely according to its orientation to the axis of stress.

The maximum shear stress hypothesis is easy to visualise when regard is given to the effects of overstrain, which are essentially of a shearing and directional type, and an inspection of the process of deformation of single crystals or the development of Luder lines and strain bands in mild steel at the point of yield leaves little doubt that so markedly directional an effect must spring from some directional cause.

On the other hand, the suggestion that in other polycrystalline metals the cause of elastic breakdown under what is necessarily a directional stress system should be a non-directional or scalar quantity, requires some adjustment of elementary conceptions. For this purpose it is helpful to realise that metal, even when in a statistically isotropic condition, consists of an aggregate of crystal grains, each essentially directional in its physical properties, but arranged with random orientations. Each crystal grain can be regarded as a member of an extremely complex structure, capable of transmitting force (or stress) more readily in some directions than others, and capable of plastic extension in some directions more than others. Under these circumstances the stresses between individual grains must vary over a wide range in magnitude, direction, type and sense, and when any individual grain reaches the limit of its own elastic strength it will affect the distribution of stress among its neighbours and so ultimately over the whole aggregate. It seems likely, therefore, that the local stresses through the bodies and across the boundaries of the grains will be of quite a different order from the statistical average stress applied to the aggregate, and will bear little relation to its direction. It does not, therefore, seem unreasonable to suggest on statistical grounds that the criterion of elastic breakdown is a scalar rather than a vector quantity, and that this criterion is closely associated with the statistical distribution of some such quantity as strain energy through the crystalline aggregate. This argument cannot, of course, be applied to the case of material in which the arrangement or properties of the crystal grains are not statistically isotropic.

Between the two energy hypotheses there is nothing to choose on grounds of direct experimental evidence, largely because under normal experimental conditions the difference between total resilience and shear resilience, which is the volumetric resilience, is relatively

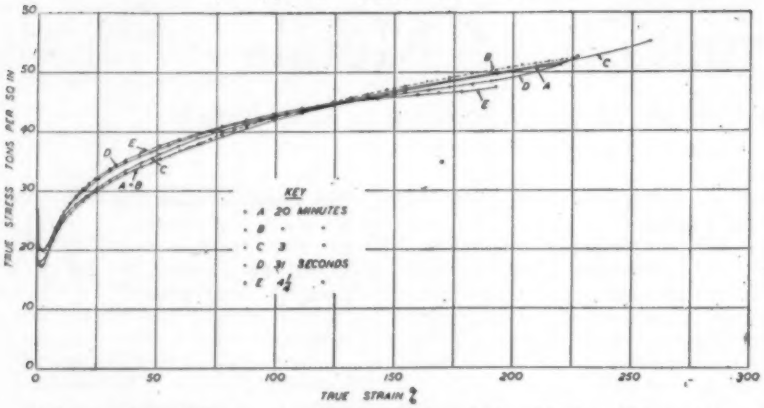


Fig. 1.—Speed effect on tru e stress strain relationship for mild steel.
Reproduced from the Fourth Progress Report on Deep Drawing Research, p. 5 (I.A.E.), No. 9177B.

small. There does, however, appear to be good reason for the exclusion of this volumetric resilience. Whatever the cause of elastic breakdown, its effect is essentially distortional and not volumetric, and distortion is purely a manifestation of shear strain. It is contrary to all physical experience that shear strain should exist without a system of shear stress, and it is therefore inconceivable that plastic flow should occur under a system of hydrostatic stress. If volumetric energy by itself cannot produce plastic flow it is clear that the total elastic energy cannot be the universal criterion of its inception. On the other hand, a system of simple shear which involves no volumetric change or volumetric resilience is a very common cause of elastic breakdown. Since, moreover, the effect of this breakdown is purely distortional, it is reasonable to conceive that its cause is also distortional. On the whole, therefore, there appears to be sufficient evidence to justify a preference for shear resilience as the criterion for the inception of plastic strain in a statistically isotropic material. It is well to point out that this shear resilience hypothesis does not really conflict with the shear stress hypothesis ; it is, in fact, a logical generalisation of it to the case of random poly-crystalline materials.

The limitation of this hypothesis to isotropic material is important, because, in general, the conditions for plastic flow in material which is not effectively isotropic are more complex and are certainly not covered by any of the stress, strain or resilience hypotheses hitherto proposed. To emphasise this point, it is only necessary to refer to the Bauschinger effect. A metal which has been overstrained in one direction is markedly different in its response to stress in different directions. This important fact will need to be considered in detail at a later stage, but at the risk of anticipation it may be stated that its explanation can be found in the non-uniform local distribution of internal stress and strain which is itself the basis of our conception of shear resilience as the general condition of entry to the plastic range.

Conditions of Rupture

When we turn to the other limit of the plastic range—namely, the intervention of ultimate rupture—we do not find it possible to prescribe a single condition or even a related set of conditions to cover all cases. In many cases rupture occurs at a particular value of the tensile stress, as has been demonstrated by Maier and by Morrison, among others, under various combinations of applied stress. In other cases there is clear evidence that rupture is due to shear stress. In the case of mild steel under tension, rupture may apparently occur from either cause according as the specimen is in the form of a circular bar or a thin strip. Some authorities have expressed the view that rupture occurs only when either the strain or the strain work has reached a specified value, but there is ample evidence (from the N.P.L. and elsewhere) that neither of these criteria is valid. Tensile tests[1] on mild steel following varying amounts of torsional overstrain suggest what is after all a very natural conclusion, that rupture may occur either by tensile stress or by shear stress, according to which first reaches the limit for the material. These experiments suggest also that while the tensile strength has apparently a fixed value for a material, the shear strength is modified and may be substantially reduced by overstrain. This fact, which is important because of its influence on the effective plastic range, can be explained in terms of the conception of "crack" orientation recently enunciated by Zener and Hollomon.

The subject of rupture is one which, curiously enough, has received less attention from research workers than it deserves. In most practical applications, however, tensile stress is the critical consideration, and the extension of the effective range of plastic deformation in technical processes of fabrication is generally achieved by some device which reduces the tensile stress within safe limits. The sinking of tubes and the deep-drawing of metal sheet are familiar cases in point.

Since the range of plastic deformation is bounded at the two ends by conditions depending on entirely different properties of the material, its extent will necessarily vary widely between different materials and different systems of impressed stress. In cases, for example, where the conditions of rupture intervene before elastic breakdown the material behaves in a brittle manner and there is no plastic range. On the other hand, with ductile materials under predominantly tensile conditions the lower the yield-point in relation to the true ultimate tensile strength the greater will be the available plastic range. And in any case the plastic range is substantially greater when the system of applied stress is predominantly compressive. Technical advantage is taken of this fact, of course, in such a process as the Rockrite method of tube-rolling as compared with tube-drawing. It may be objected that in the case of wire-drawing on the other hand, certain advantages accrue from the use of back-tension. But these advantages do not include the possibility of increasing the draft, in fact the permissible draft is substantially decreased by back-tension.

Characteristics of Plastic Deformation

Having discussed the limits of the plastic range, let us now consider the characteristic features of the deformation which occurs within that range.

1 *J.I.S.I.*, 1939, No. II, p. 181.

1. The strains associated with plastic flow are large compared with elastic strains, and do not disappear when the stress is removed. It should be pointed out that the material does not lose its elastic properties—i.e., its instantaneous resistance to strain—as can be demonstrated by vibrational methods of measurement, but the elastic strains are masked by the greater "permanent" strains and for ordinary purposes can be neglected.

2. Plastic strains take time to develop. The rate of deformation depends on the material, on the temperature, and on the amount by which the applied stress exceeds the current value of the elastic strength of the material. With steel at ordinary temperatures (Fig. 1) the rate of strain increases so rapidly with the stress excess that stress/strain curves at all speeds of straining possible in ordinary testing machines vary but little from one another. On the other hand, at high homologous temperatures measurable strain continues for a long time, as is shown by the phenomenon of creep, though in all cases the strain rate increases more rapidly with the stress excess than can be explained in terms of fluid viscosity.

If we regard strain instead of stress as the impressed condition, then plastic strain may be conceived as a relaxation phenomenon. If we assume the strain is applied instantaneously, the stress is initially very high and the strain energy entirely elastic. The more overstressed crystal elements overstrain rapidly, so relieving their own stress and causing a redistribution throughout the structure, while the energy absorbed in the overstraining process is provided at the expense of the elastic energy, so that the mean stress falls. This process continues at a progressively slower rate as the stresses in the overstrained crystals fall to their elastic limit, and when—if ever—this condition is reached the strain ceases. There is evidence that certain grain elements become overstrained and set up a process of relaxation in a small way even below the technical elastic limit, for refined measurements of strain and tests of damping capacity show departures from linear and completely reversible strain even at low values of the applied stress.

TABLE I.—ENERGY ABSORBED IN OVERSTRAIN.
(G. I. Taylor.)

Metal.	Heat Equivalent of Strain Work, G. Cal. G.	Absorbed Energy, %.	Released Energy, %.
Copper	5·5	—	9
	0·82	9	—
	0·96	7·5	—
	6·2	8·6	—
	14·1	8·1	—
Iron	7·8	—	15
	1·1	13	—
	3·2	9	—
	9·6	7	—
Aluminium	1·2	7	—
	1·8	5	—
	11·8	—	9·8
Brass 70/30	4·67	—	16
	2·93	—	15
Nickel	13·9	—	5·6

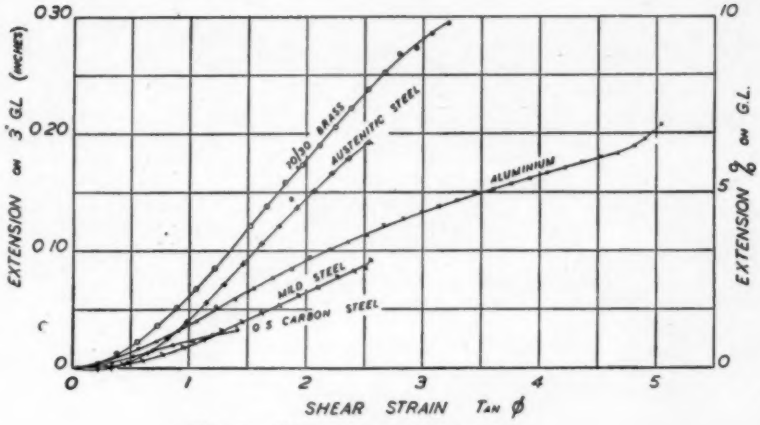


Fig. 2.—Elongation under torsion.
Reproduced from I.A.E. Report No. 9177B, p. 10.

3. The work absorbed in the development of plastic strain reappears largely in the form of sensible heat, but it has been shown by Taylor (Table I) that about 10% remains in some potential form in the material. Having regard to the relatively high and multidirectional stresses in the constituent grains, it is certain that some of this residue takes the form of dispersed elastic energy in the system, though there is still a considerable unaccounted balance to provide a problem for the metallurgist.

4. Plastic strain may be regarded in two ways—either as the rate of straining or creep in relation to time or as the resultant amount of distortion necessary to restore equilibrium between the intrinsic resistance of the material and the applied stress. Deformation continues, of course, until this balance is achieved, and under a given system of stress will continue indefinitely unless the effective strength of the material increases with strain sufficiently to resist this stress. Any conception of a static stress-strain relationship within the plastic range involves, therefore, the conception of strain-strengthening, or strain-hardening as it is commonly termed. A detailed examination of this important phenomenon comes appropriately at a rather later stage.

5. The directions of plastic strain are related to the directions of the applied stress system. Provided that the material behaves isotropically, it is clear on grounds of symmetry that the principal directions of strain will coincide with the principal directions of stress. This condition will also hold in cases where the material, though not isotropic, has properties which are symmetrical about the axes of stress, as, for example, in a drawn or rolled bar which is overstrained in tension. But where material has directional properties either inherent or developed it cannot be expected that the axes of stress and strain will coincide. The ears, for example, which form on cups drawn from a directionally rolled sheet result from unsymmetrical strain, and the change of length which occurs during overstrain in pure torsion (Fig. 2) is due to the directional properties which develop during the actual process of twisting.

6. Plastic strain is distortional in character; it involves a change in shape and not (appreciably) a change in volume. It is therefore essentially directional, and is a manifestation of angular or shear strains in which changes of length only occur to the extent necessary to conform to these strains.

The directional distributions of stresses and strains are conveniently shown by means of Mohr circle diagrams. In the stress circle diagram the three principal stresses are plotted from a single origin and three circles are constructed as shown in Fig. 3. The normal and shear components of stress on any plane are then represented

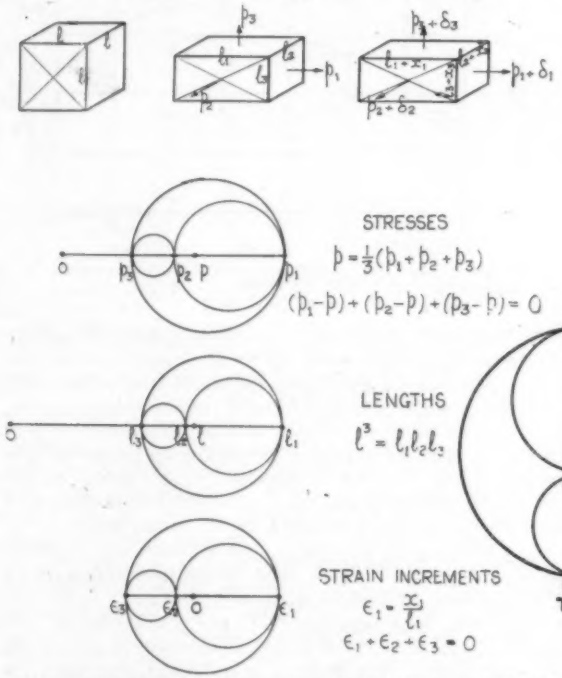

STRESSES
$p = \frac{1}{3}(p_1 + p_2 + p_3)$
$(p_1 - p) + (p_2 - p) + (p_3 - p) = 0$
LENGTHS
$l^3 = l_1 l_2 l_3$
STRAIN INCREMENTS
$\epsilon_1 = \frac{x_1}{l_1}$
$\epsilon_1 + \epsilon_2 + \epsilon_3 = 0$

Fig. 3.—Mohr circle diagrams for plastic stress and strain.

by the co-ordinates of an appropriate point either on or in the interspace between these circles. In particular, the radii of the circles represent the principal shearing stresses and the radius of the enveloping circle the maximum shear stress. Incidentally, the shear resilience is represented to an appropriate scale by the sum of the areas of the three stress circles.

If, instead of the principal stresses, we plot the lengths of the sides of a strained unit cube, an exactly similar construction enables us to measure the stretch and angular distortion of any row of particles. In particular, the radii of the three circles represent the distortions of the diagonals of the faces of this unit cube, and the deformation of the cube as a whole can as well be represented in terms of the distortion of these diagonals as by the changes in length of its sides.

Although this construction is valid for any deformation, however great, it is generally more convenient to consider relatively small increments of distortion due to small changes in conditions, and for this purpose a diagram of strain increments can be constructed by plotting increments of the principal strains. The radii of the circles then represent corresponding increments of angular distortion.

Since by hypothesis we are only concerned with shear stresses and with distortional strains, the positions of the origins of the stress and strain diagrams are of no significance for our purpose; on the other hand, the proportions of the circles themselves are of prime importance as defining the system of distortional stress and distortional strain.

7. The directional distribution of strains, which is defined by the proportions of the circle diagram, depends primarily on the system of applied stress. In simple shear, for example, the diagram for an isotropic material consists of two equal circles enclosed in the third, while in simple extension, since the lateral shrinkage is the same in all directions perpendicular to the axis of tension, two of the strain circles are identical and the third shrinks to a point. Although the strain distribution is primarily controlled by the stress system, it depends also on the response of the material in different directions to the distortional—i.e., the shear stress.

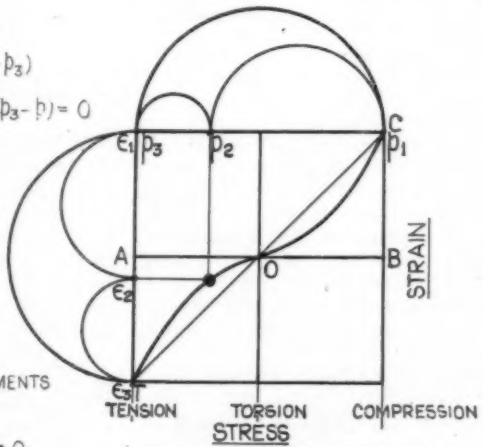


Fig. 4.—Lode diagram.

(*a*) If, for example, the maximum shear stress hypothesis were carried to its logical conclusion it would contemplate a material which responds only to shear stress of the critical value and which is able to resist strain under any lower stress. In this case the plastic strain would take the form dictated by the maximum shear stress irrespective of any other, and would therefore be a simple shear, giving the symmetrical circle diagram characteristic of this simple shear.

(*b*) If, on the other hand, the material is such that during deformation the direction of slip on any plane coincides with the direction of shear stress on that plane—a condition obviously demanding an isotropic material—then it can be proved that on every plane the amount of slip will be proportional to the intensity of shear stress and the strain circle diagram will therefore be exactly similar to the stress circle diagram.

The actual distribution of strain can, of course, be determined experimentally, and from tests carried out under different systems of stress Lode, and later Taylor and Quinney, have provided data on which these alternative assumptions can be compared. For this purpose the results are plotted on a "Lode diagram" (Fig. 4), which in effect relates the proportions of the stress and strain circle diagrams. According to hypothesis (*a*) the results should lie on the broken line T A B C, while according to the second hypothesis they should lie on the straight diagonal line T C. The results obtained by Taylor and Quinney (Fig. 5), which are more comprehensive and discriminating than Lode's own, show that the conception of maximum shear stress is quite erroneous while the second hypothesis gives at least a first approximation to the truth. It is, in fact, notably consistent with the behaviour of non-hardening materials like glass and lead, but shows a systematic divergence in the case of metals which harden under strain. It may be mentioned in passing that this divergence could be explained if it could be shown that in a material in a

given condition the rate of strain-hardening has directional properties, being greatest in that component shear element for which the shear stress is least.

Strain Hardening

It is a matter of experience with almost any metal that when subjected to plastic strain its resistance to further strain in the same direction is increased. The increment of elastic strength resulting from a given amount of plastic strain is a characteristic of the metal, and the greater this increment in relation to the strain the greater is its rate of strain-hardening.

Strain-hardening clearly presupposes some internal structure of the material, for it is difficult to conceive how the physical properties of an amorphous material could be modified by a rearrangement of its molecules, which constitutes strain, and in a metal there is no doubt that the phenomenon of strain-hardening is associated with crystalline arrangement or disarrangement either within or between the individual crystal grains.

The basis on which we measure strain-hardening, which is essentially an increment of elastic strength, must logically depend on the criterion which we accept

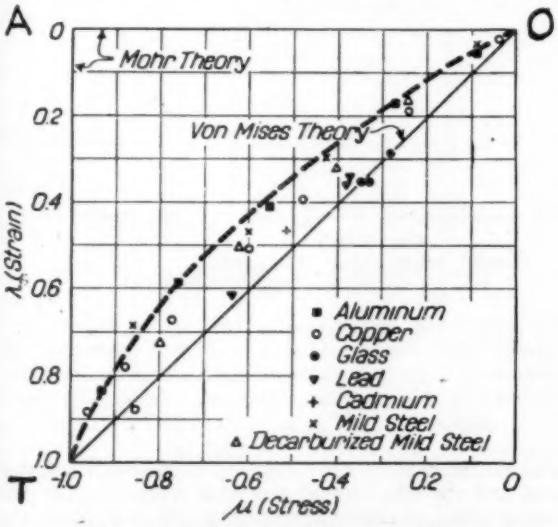


Fig. 5.—Lode's diagram for plastic flow.

as measuring this elastic strength. According to the shear stress hypothesis, for example, we should measure strain-hardening as the increment in maximum shear stress, and if it is assumed that strain-hardening is a function of the strain it is natural to relate this increment to the corresponding maximum shear strain. Hence, the appropriate strain-hardening characteristic for a material whose limiting condition is shear stress would be a curve showing maximum shear stress in terms of maximum shear strain. If carried to its logical conclusion, the shear stress conception requires that this curve shall be independent of the system of applied stress. A comparison of curves obtained in tension and in torsion shows that this prediction is not justified with polycrystalline metals, and the fact that with single crystals the amount of shear on planes of slip bears the same relation to the shear stress *on these planes* in tension, and compression does not justify the *maximum* shear stress hypothesis.

If, on the other hand, we accept shear resilience as the criterion of elastic strength it is logical to regard the increment in this resilience as a measure of strain-hardening, and since plastic strain involves strain-work, which is of the same physical dimensions as resilience, it would be rational to measure the strain-hardening rate of a material in any condition in terms of the ratio of the increment in resilience (S) to the corresponding increment of strain work (W), which produces it, so that the strain-hardening rate $= \frac{\delta S}{\delta W}$, the slope of the curve (Fig. 6), in which S is plotted against W. If S is a function of W alone, irrespective of any other conditions, this curve will be the same under all systems of stress, whether plotted, for example, under tensile, compressive or torsional conditions. If different conditions give different curves it does not follow that the conception of shear resilience is erroneous, but it does follow that strain-hardening is not a function of strain work alone, and the usefulness of any single strain-hardening curve will then be limited to the particular system of stress under which it has been obtained.

The values of S, W used in plotting this type of curve need to be found by calculation from experimental measurements of stress and strain. It would therefore be more convenient if appropriate stress and strain values could be plotted direct, provided always that values can be chosen which are representative for this purpose.

Now the shear resilience S is proportional to the sum of the squares of the three principal shear stresses—i.e., of the three stress circle radii. Hence, if S is a measure

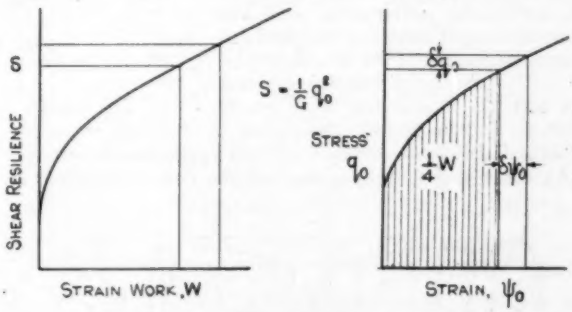


Fig. 6.—Strain hardening characteristics.

of the elastic strength, so also will be the r.m.s. value of the shear stress, q_0, say, and an increment of elastic strength or hardening can be expressed as δq_0. If now the strain increments resulting from an increment δq_0 in the stress q_0 are plotted in the form of a circle diagram the r.m.s. value $\delta\psi_0$ of the principal angular strains—i.e., of the three strain-circle radii—can easily be obtained.

It can be shown that the rate of strain-hardening, which has been defined as $\frac{\delta S}{\delta W}$, is exactly proportional to the ratio $\frac{\delta q_0}{\delta\psi_0}$ and can therefore be measured as the slope of the curve in which q_0 is plotted against ψ_0 (Fig. 6). Hence, according to the shear resilience conception, q_0 can be regarded as the representative stress and ψ_0 as the representative strain and the curve relating q_0 to ψ_0 as the strain-hardening characteristic. The usefulness of this curve is enhanced by the fact that the specific

strain work involved over any range of straining may be measured by the corresponding area under the curve $W = 4\int q_o \, d\psi_o$. As in the case of the S/W curve, this strain-hardening characteristic will not necessarily be the same for every system of stress. This is a matter for experiment with different materials, though it can be shown that a single characteristic will cover all systems of stress for a given material if the strain-hardening rate of this material is the same in all directions of shear.

Let us now see how this characteristic can be plotted from different forms of test.

For this purpose the value of the representative stress can be calculated by appropriate formulæ from measurements of applied loads and corresponding dimensions, care being taken that the calculated values represent the true stress having regard to the current dimensions and not the nominal stress corresponding to the initial dimensions of the test specimen. In a similar way, either the representative strain ψ_o or more simply the strain increment $\delta\psi_o$, can be computed from measurements of extension, twist, etc., by the use of other appropriate formulæ. The procedure may conveniently be illustrated by considering the simple tensile test, since this demonstrates particularly well the importance of adopting true and not nominal values of stress and strain.

Although one of the oldest forms of test, the tensile test still provides fuel for controversy, and a recent discussion in London revealed marked differences of opinion and appreciation among engineers and metallurgists. At the risk, therefore, of checking the thread of our present argument, though in no way overstepping the bounds of our subject, it is worth while to consider this test in some detail.

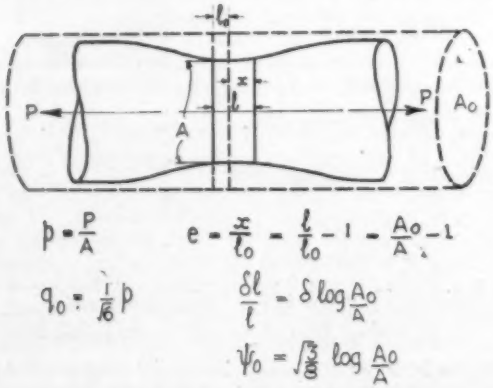


Fig. 7.—Diagram illustrating necking.

The traditional so-called stress-strain curve in which the load per unit of initial area is plotted against the mean extension per unit length of specimen has, of course, very little direct physical significance. As will be seen from Fig. 7, the load per unit of initial area is not the stress at any point within the plastic range, and the mean extension ceases to be a measure of the effective plastic strain as soon as necking commences. Once a neck has formed the subsequent strain is confined to the region of the neck, and since this is the only part then undergoing deformation the measurement of strain should be confined to the necked section. Changes of length on a very short length are difficult to measure,

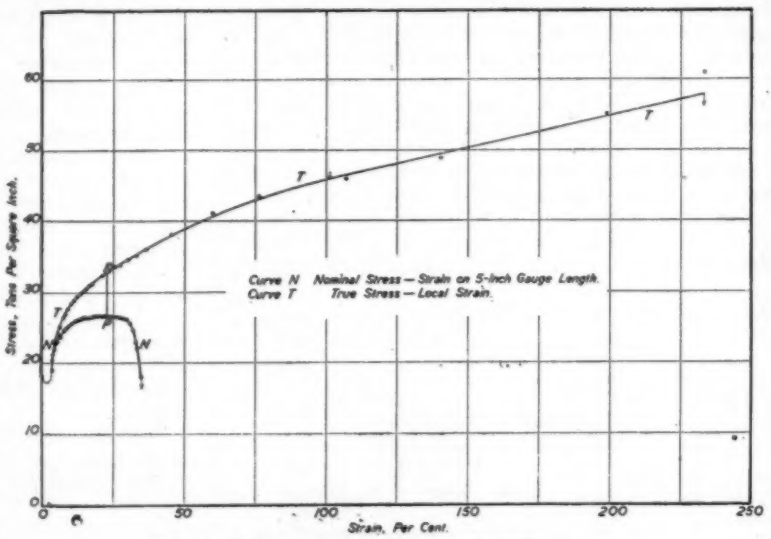


Fig. 8.—Tensile stress strain diagrams.
Reproduced from p. 189 of "Tensional Effects of Torsional Overstrain in Mild Steel" (*Jour. I.S.I.*, vol. CXI, 1939).

but, since the sectional area changes in exact conformity with the length, it is valid and convenient to measure changes in diameter of a circular bar. This also enables us to compute the true stress. In fact,

$$p = \frac{P}{a} \text{ and } e = \frac{a_o}{a} - 1.$$

Hence, by taking successive measurements of the load and the diameter at a section where straining is taking place, the true stress, true strain relationship for the material can be obtained without any axial measurements at all. This procedure involves a special but quite simple technique, and results obtained with mild steel (Fig. 8) show how different is the true stress-strain curve from the rescaled load-extension diagram. Points of interest in connection with this true curve are :

1. The point of maximum load and incipient necking is seen to have no special physical significance ; it is, in fact, the point of tangency of a line drawn from the point on the base line corresponding to zero length.

2. In mild steel at least the amount of effective strain which occurs during the process of necking is much greater than that which has occurred previously, and in most technical processes where the amount of deformation is substantial, the post-necking portion of the curve is of primary importance.

3. The actual breaking strength of the metal is much greater than the conventional "ultimate tensile strength."

True stress-strain curves for a number of different metals are shown in Fig. 9.

In order to make use of plastic properties in calculations, a number of attempts have been made to plot the tensile stress-strain curve in such a way as to give some kind of linear relationship which could be embodied in a simple empirical formula. Some of the proposals are illustrated in Fig. 10, which has been plotted from data obtained by Stead[2] from a mild steel bar. The only curve which approximates to a straight line is that relating true stress to proportional change in diameter, and this only becomes linear after a substantial amount of overstrain. With other materials attempts to "bring the results into line" are even less successful, and on general

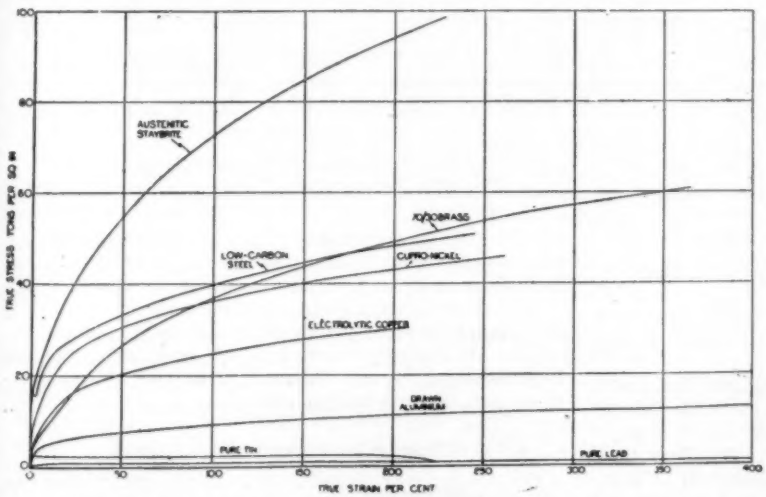


Fig. 9.—Tensile true stress-strain curves.
Reproduced from I.A.E. Report No. 9177B, p. 3.

grounds it seems unlikely that any single form of empirical relationship can cover the tensile properties of the widely different materials of technical importance. There is, therefore, no advantage in standardising any form of stress-strain curve other than one which has a direct physical significance. This the true stress-strain curve clearly has, and the others so far considered have not.

But this true stress-strain curve does not provide all the information we may need in a readily accessible form; its slope does not represent the strain-hardening rate, which is a matter of primary concern in the plastic range, and its area does not represent the specific strain-work. If, however, a curve is drawn (Fig. 11) in which the true stress $\frac{P}{a}$ is plotted against $\log \frac{a_o}{a}$, it can be shown that—

1. The slope at every point is directly proportional to the rate of strain-hardening, since

$$q_o = \sqrt{\frac{1}{6}}\, p \quad \text{and} \quad \psi_o = \sqrt{\frac{3}{8}} \log \frac{a_o}{a},$$

2. The area under the curve is a direct measure of the strain work.

3. Any initial overstrain simply displaces the curve without changing its shape.

This curve when suitably scaled is in fact the strain-hardening characteristic according to the conceptions advanced above, showing the representative stress in terms of the representative strain, and in this form it is suitable for comparison with corresponding curves obtained from other forms of test. It is therefore suggested that in cases where the tensile test is made not merely as a commercial standard of comparison, but with the purpose of ascertaining the intrinsic physical properties of a material over an extended plastic range, the methods of measurement and plotting should be in accordance with those described above. Strain-hardening characteristics for the metals shown in Fig. 9 are plotted in Fig. 12.

In torsion tests the normal torque-twist curve (Fig. 13) is not so markedly different from the true stress-strain curve as the corresponding tensile curve, and the angle of twist is in fact directly proportional to the true representative strain, but the surface shear stress needs to be obtained from the torque by a graphical construction such as that proposed by Nadai. The actual values of the representative stress and strain are

$$\sqrt{\frac{1}{2}}\, s \quad \text{and} \quad \sqrt{\frac{1}{8}} \tan \phi,$$

where s is the surface shear stress and ϕ the surface angle of shear.

Under more complex systems of stress the representative stress and increments in the representative strain can be found from ordinary experimental measurements by

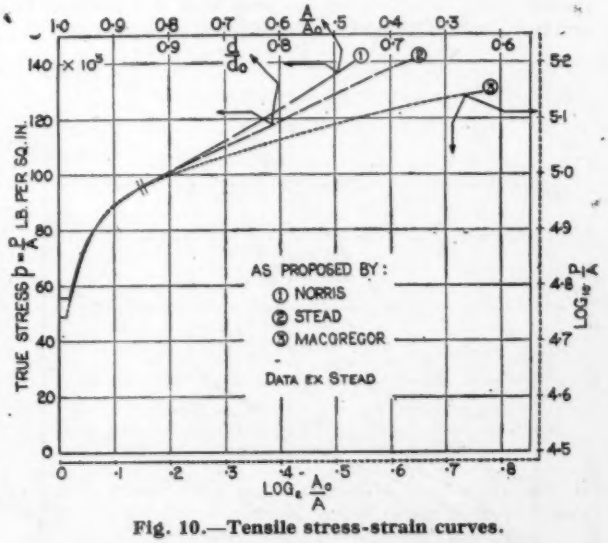


Fig. 10.—Tensile stress-strain curves.

fairly simple formulæ, and the strain-hardening characteristic plotted by simple summation.

It will be interesting now to compare the characteristics obtained from different forms of test in order to ascertain to what extent they coincide or to what extent the strain-hardening rate of overstrained material has directional properties. The only reliable data available at the present time refer to simple tension, simple compression, and simple torsion, but since these represent

2 *Jnl. Iron and Steel Inst.*, CVII, p. 377 (1923, No. 1).

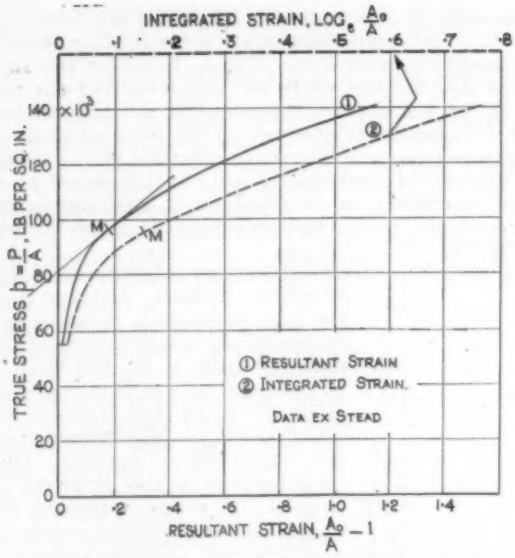

INTEGRATED STRAIN, LOG$_e$ $\frac{A_0}{A}$
TRUE STRESS $b = \frac{P}{A}$, LB PER SQ. IN.
RESULTANT STRAIN, $\frac{A_0}{A} - 1$
① RESULTANT STRAIN
② INTEGRATED STRAIN.
DATA EX STEAD

Fig. 11.—True stress-strain curves in tension.

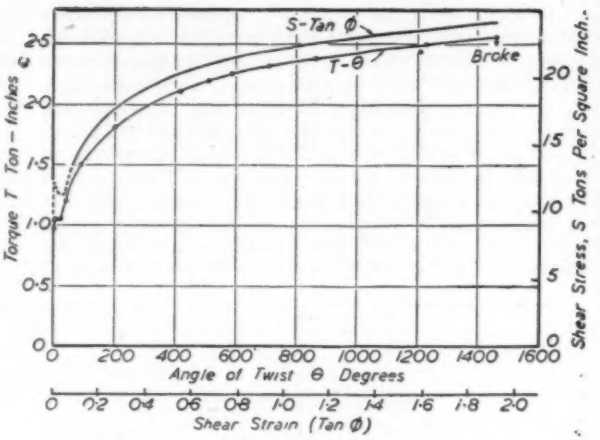


Fig. 13.—Torsional shear characteristic.
Reproduced from p. 190 of "Tensional Effects of Torsional Overstrain in Mild Steel" (*Jour. I.S.I.*, vol. CXL, 1939).

the extreme proportions of the distortional stress system they should give some idea of the full range of any divergence.

Published results for tension and compression show generally a close similarity between the two curves, though a few results with mild steel and copper suggest that the rate of hardening in compression is less than that in tension after necking has commenced. A comparison (Fig. 14) of curves for mild steel in tension (A) and in torsion (T) shows a more definite and progressive

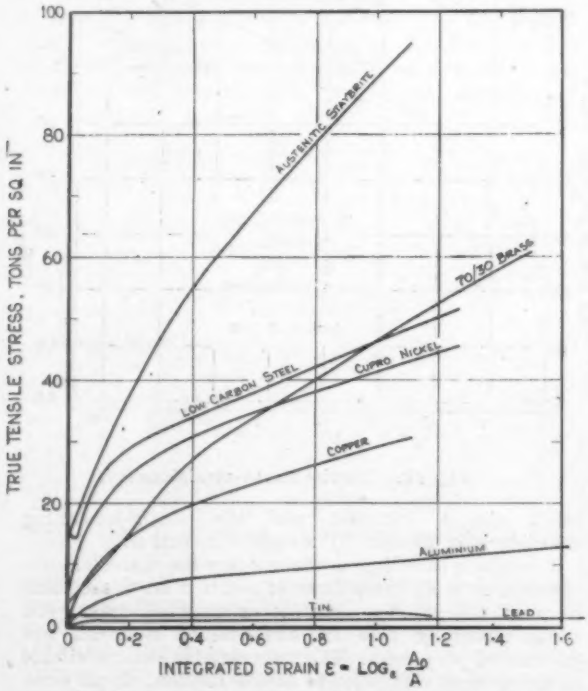


Fig. 12.—Strain hardening characteristics in tension.

divergence. In the earlier stages of strain torsion and tension appear to produce about the same amount of hardening while under more severe strain the torsional rate is reduced. These divergencies suggest either that directional properties have developed or that the stress system after necking in tension is not so simple as has been assumed. In the interests of fuller understanding there is need for a further investigation of these points.

Change in Direction of Stress

Our comparison of strain-hardening characteristics has shown that the representative strength of a material is not a single-valued function of the strain or strain work to which it has been subjected. And these characteristics have been obtained by continuous straining in the same direction and sense. When for any reason the direction of straining is altered or reversed the disparity is much more marked, particularly during the earlier stages of straining in the new direction. After torsional overstrain, for example, the tensile characteristic is at first quite different from the form it would have taken if the same amount of hardening had been produced in tension. But the most notable difference is that which occurs following the direct reversal of strain, well known as the Bauschinger effect, illustrated in Fig. 15. If a bar is overstrained in tension its resistance to compression is reduced, if a bar is overstrained in torsion its resistance to reversed torsion is reduced.

Several theories of strain-hardening have been developed, based on lattice distortion, mosaic adjustment, amorphous degeneration, grain boundary effects, and other hypotheses, between which the engineer is less qualified to judge than the metallurgist. But not one of these theories seriously attempts to explain this very marked directional behaviour. It is, of course, a clear indication of anisotropy in the material, but this anisotropy is apparently difficult to explain on metallurgical grounds. If, however, we consider the problem from the standpoint of stress and strain without any metallurgical preconceptions, the phenomenon seems to be an almost inevitable result of internal stress.

It has already been emphasised that the grain elements of a polycrystalline metal are under stresses differing widely in magnitude and type. There must therefore be

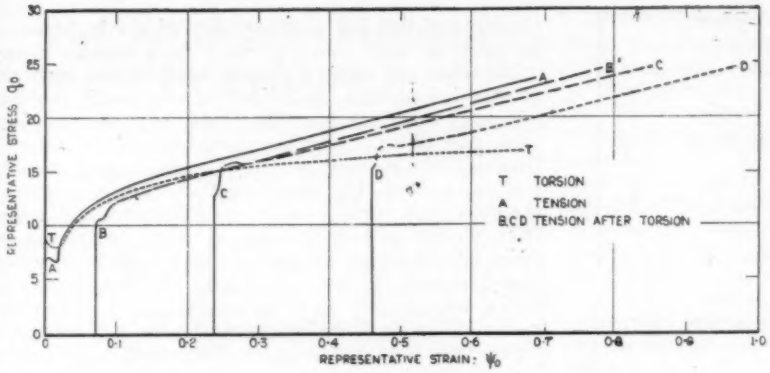


Fig. 14.—Torsion, tension and tension after torsion curves.

between adjacent elements differences in normal stresses or in shear stress or both. Now differences in normal stress from fibre to fibre are characteristic of bending, and differences in shear stress are characteristic of torsion.

Let us consider first the effect of overstrain in bending in a bar of material which for simplicity can be regarded as non-hardening. The distribution of tensile stress is linear until the yield-point is reached at the outer surface as indicated by (1) in Fig. 16. Thereafter, the distribution takes the discontinuous form shown as (2). If at this stage the bending couple is removed the relaxation is elastic, since the stress becomes everywhere lower than the yield, and the distribution after release of load will correspond to (3). It will be noticed that at this stage there is a distribution of internal stress although no load is applied. If now a bending couple is applied in the reverse direction the stress will continue to change elastically until the distribution (4) is attained, at which point yield occurs in compression at the originally tensile surface, and in tension at the originally compressive surface. The couple required to produce this reversed yield is less than that released in the ratio B C : B A, and less than the couple producing initial yield in the ratio B R : C A. Hence the initial overstraining of the bar has produced in it a weakening in its elastic resistance to bending in the opposite direction. Further overstrain in the reverse direction produces a distribution such as (5), and if the load is then released and reapplied in the original direction the stress distribution at yield will be then shown as (6). If the strains corresponding to these couples are plotted together they give cyclic curves of the form shown in Fig. 17, bearing a marked family resemblance to those of Fig. 15, associated with the Bauschinger effect.

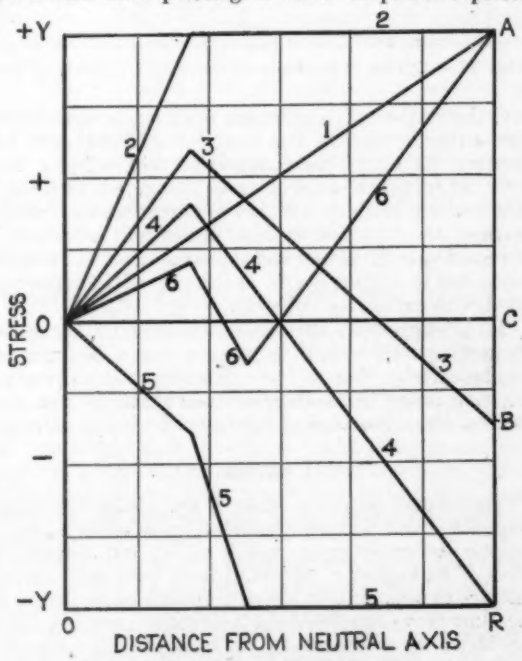


Fig. 16.—Plastic torsion or bending.

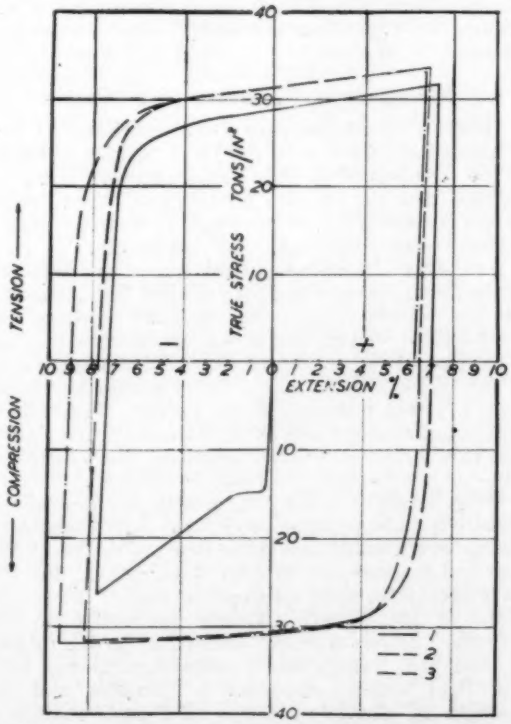


Fig. 15.—Cyclic curves for mild steel—tension/compression (Bauschinger effect).

A consideration of shear stresses in torsion would lead to results of an exactly similar kind both as regards weakening after reversal of twist and the cyclic form of stress-strain curve.

The extension of these results to any case involving reversal of strain is a simple matter. The reversal of strain over any local region across which the internal stress, either direct or shear, varies from point to point will involve an element of one or other of these effects,

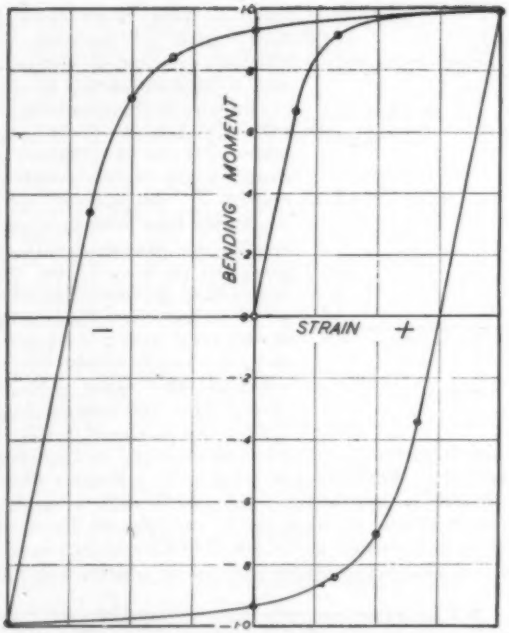


Fig. 17.—Cyclic overstrain in bending. Arbitrary scale.

and the statistical result when these are integrated over the whole volume of the material will naturally have general characteristics common to both effects. Moreover, whenever the axes of strain change, as, for instance, when a bar initially twisted is subsequently pulled in tension, the direction of shear strain will necessarily be reversed on some planes and the same effect will therefore arise, but to a lesser degree as the axes of the consecutive strains more nearly coincide.

It is suggested, therefore, that the rather elusive Bauschinger effect both in its pure and hybrid forms, is fundamentally due to the non-uniform distribution of internal stress in an over-strained material and is not necessarily a function of strain-hardening at all.

Conclusion

That must conclude what I am afraid has been a superficial and perhaps somewhat speculative account of plastic deformation in metals as viewed through the eyes of an engineer. It would have been interesting to inquire to what extent the conceptions embodied in this account prove serviceable in their application to technical problems, to what extent, for example, they enable us to predict the roll-pressures required for different materials, the punch loads required to press them, the changes in thickness which occur in the drawing of sheet or the sinking of tubes, or the distribution of internal stresses in a gun-tube after auto-frettage. Unfortunately, these and other technical problems of application do not readily yield even to mathematical analysis, and would be scarcely suitable to present in an oral discussion.

It so happens that these problems are generally easier to treat on the shear-stress hypothesis, and it is possibly for that reason that this hypothesis has retained its popularity. It also happens that in those problems which have proved capable of solution under both hypotheses there is no great difference between the results, and this has possibly reduced the insistence of designers on what would no doubt be a sounder theory.

Moreover, in most technical applications involving plastic deformation, as indeed in almost all problems of engineering design, the relatively simple basic principles are masked by secondary effects, such as friction, non-uniformity of properties and working tolerances, with the result that even a perfect basic theory would require special modifications and corrections to suit each individual problem. In the present stage of knowledge and development it must be admitted, therefore, that the designer is fully justified in working, as he does, largely on empirical data and in assessing materials, as he does, largely on the basis of simulative rather than fundamental tests. Nevertheless, he is ready and anxious to adopt more scientific methods as soon as the metallurgist and the mechanical researcher can provide him with the necessary tools.

Zinc Development Association

THE Zinc Development Association, which has recently published a report for 1943-44, was formed in 1938 to provide users of zinc with a comprehensive information service and so to bring about a greater appreciation of the properties and applications of zinc. In 1941 the Zinc Alloy Die Casters Association was formed, which was followed last year by the formation of the Zinc Pigment Association. The report deals with the activities of these associations and also gives an indication of the services offered to users of zinc and zinc products. Only a limited number of copies of this report can be issued, and those interested should communicate with the Secretary, Zinc Development Association, Lincoln House, 15, Turl Street, Oxford.

Mr. Horace W. Clarke and Düren

Düren, a town in the path of the American first Army, is associated with one of the epoch-making discoveries in the evolution of the light metal industry. It was here in 1906 that the German metallurgist, Wilm, working at the Kaiser Wilhelm Institute, discovered—quite by accident—the aluminium alloy Duralumin.

At the time, the German Government was apparently not unduly impressed and they allowed Wilm to keep the patents. World rights (other than for Germany itself) were sold to Vickers and it was Mr. Horace W. Clarke (Chairman of James Booth & Co. Ltd., Birmingham, and of the Wrought Light Alloys Development Association), then a young metallurgist on Vickers' staff, who not only negotiated the sale of the manufacturing rights to America, France and other countries, but was the first man outside Germany to make Duralumin.

Wilm bought a poultry farm with the proceeds and retired to raise pedigree stock. He little thought that his discovery would herald the dawn of the Light Metal Age and revolutionise aircraft construction. He would have been even more surprised to hear of the post-war plans of Mr. Horace Clarke's Association to build "Portal" houses of aluminium and to further its use in shipbuilding, transportation and structural engineering. The light weight, resistance to corrosion and great strength of aluminium alloys offer such obvious advantages, and a seven-fold expansion in production means that there will be no supply problem.

The Training of Personnel for Industry

CONSIDERABLE thought is being given to the training of personnel for industry. The need for such training is frequently expressed and there can be no doubt that many schemes must be prepared and put into operation as soon as there is a reasonable prospect of partial demobilisation of the Forces. A recent discussion on the subject, under the auspices of the London and Home Counties Branch of the Institute of Physics, was opened by Major F. A. Freeth, F.R.I.C., F.Inst.P., F.R.S., of Imperial Industries, Ltd.

Representing one of the largest employers of scientists in the country, and having had many years' experience of selecting and training personnel for industry, Major Freeth's address proved stimulating, important, and provocative; it contained many practical suggestions for the education and training of scientists for industry. The points to be kept in mind when making a selection were, he said, a man's general intelligence and the possibility of his development over a long period in the right atmosphere. Interviews should be kept as informal as possible, and the greatest pains should be taken to make the candidate feel at his best and at his ease. Every endeavour should be made to find out his likes and intellectual interests. The greatest allowances should be made, especially at the present time, for the effect of the war upon his educational career, and at all times the most sympathetic allowances should be made for a man who has not had much chance of general education and experience of the world, in his youth. Within industry itself, every possible effort, he said, should be made to encourage scientific and intellectual enthusiasm. When possible, the stimulus of travel and visits to scientific and technical conferences should be used.

The man in industry should be encouraged to be on particularly good terms with people in that branch of science in which he is engaged who are in the Universities. He thought that men whose performance in university examinations had been poor should not be overlooked, as there might be some good reason for this. Generally speaking, people who did well in examinations were industrious, and they may very well have brains, but occasionally success in them proved to be no more than a feat of memory. Major Freeth commended the selection work of psychologists in this war, and thought that every encouragement should be given to them to assist in similar problems for industrial recruitment. He thought the crux of the whole matter was to regard a man's education as having for its purpose "getting him into a frame of mind where he will go on building up on himself for the rest of his life, or in other words, his degree is merely an incident in his upward flight." "The other end of the scale," he said, "is the man who on obtaining his degree says: 'I'm qualified,' and potters along till he reaches his grave."

He deprecated the idea that a man was a kind of *doctor mirabilis* when he had graduated, and said that he had never been happy about the Ph.D. degree. He pleaded for more training in the writing of clear English, particularly for those who had to present reports and appreciations of other people's work; and he was supported in this by several speakers in the general discussion which followed.

A representative of a large electrical engineering firm suggested that the industrial physicist should serve an apprenticeship similar to that expected, for example, of engineers and architects. The need for the most careful selection of those entering industry with a view to occupying supervisory positions was stressed. Such men needed a wide knowledge rather than a specialised one, and universities and technical colleges were urged to educate and train men for leadership rather than for narrow vocational work. The great advantages accruing from contact with industry as part of a training scheme were pointed out, and a sandwich system of up to five months in industry each year was recommended. Attention was also called to the existing schemes, whereby students were placed in industry during the vacations.

One speaker from a large industrial concern said that the attitude of some universities was "industry must take whatever we offer," but in his view, if the University did not offer to industry men it could readily employ usefully, industry would in its turn ignore the universities and set up its own education and training schemes. This view was challenged, and several other speakers from industry stated that they did not expect entrants to their organisations from university and technical colleges to be employed on productive work until they had gained the special training and experience requisite for their particular industry—a matter of six months or more. They wanted the universities and colleges to provide them with good scientists, having broad rather than deep knowledge, and they would attend to the rest.

The audience was reminded that industry was organic, and therefore continually changing; it was being fed with a stream of new blood, and it must adapt this and direct it to its varying requirements.

Gears and Gear-Cutting Machinery

MESSRS. DAVID BROWN & SONS (HUDDERSFIELD), LTD., announce a further extension of their activities through an arrangement by which they acquire control of the share capital of Messrs. Muir Machine Tools, Ltd., of Britannia Works, Sherborne Street, Manchester. With this new acquisition it will be possible to secure the necessary specialisation in the development of gears and gear-cutting machinery, and to maintain that close association between machine builder and user that is so necessary for efficiency.

The Muir plant will be reconstructed and improved to cope with the most recent developments and urgent requirements for high-precision machines, and their future programme will include a complete range of gear-hobbing machines to cover all demands from small and medium size repetition work to turbine gear-hobbing machines with a capacity of 20 ft. diameter.

Special Directors

FIVE senior officials of Dorman, Long and Co., Ltd., Middlesbrough, have been appointed special directors of the company; they comprise Mr. D. R. Brooks, M.I.M.E. (chief agent in charge of the company's Durham collieries); Mr. R. A. Hacking, M.Sc. (controller of pro-duction); Mr. E. T. Judge, M.A. (Cantab), (chief technical engineer); Mr. A. MacLeod (commercial manager), and Mr. J. A. Millar (treasurer).

Correspondence

Press-Forged Pistons

The Editor, METALLURGIA.

Sir,—A few comments in amplification of the excellent article on forged pistons* in your November number may be of interest.

The pressed aluminium alloy piston was first developed in the United States and more recently in Germany. It is doubtful whether the primitive method of rough dummying cast billets followed by die forging under a hammer persisted during the last 10 years outside of this country for the production of pistons, except for experimental purposes. In the United States the first presses employed were an adaptation of the Ajax forging machine, used for upsetting the heads on bolts. The forging of aero-engine pistons was completed in two or three stages from cylindrical blanks. In the Ajax machines the dies are actuated by a type of crank mechanism, and it was not possible to regulate the speed of deformation with sufficient precision to permit of good forgings being obtained from cast blanks. Wrought stock, therefore, was employed and bar rolled from cast cylindrical billets was selected as being more satisfactory than extruded stock. Extruded round bar usually shows appreciable variation in the grain formation on the cross-section. There frequently are concentric rings of fine attenuated grains alternating with relatively coarse grain bands. Sometimes incipient piping occurs, and its cause is not always easy to trace. Some German manufacturers overcame the disadvantages presented by these inherent characteristics of the extruded bar by using flat extruded stock of rectangular section cut off into square biscuits, which were subsequently pressed to size in the die by a flat blanking tool. The grain flow would be at right angles to the flat faces in the blanks made from round stock, and parallel to them when flat stock was used. In the latter case, the direction of the grain flow in the blank would be generally normal to the direction of metal flow during forging. Such orientation of the structure would be expected to result in the metal being more evenly stressed when forging pistons than if the grain flow were at right angles to the blank face.

The employment of toggle or hydraulic presses for forging gives such a high degree of control over the rate of deformation that it is possible to use cast blanks provided the grain is uniformly fine, and there is no serious segregation of the constituents. With either type of press the rate of deformation is sufficiently low to ensure adequate working throughout the metal during the forging operations. Previous working of the stock is not necessary or desirable, as it is after hammer forging, when the rate of deformation may be much too high to permit of the metal being worked uniformly.

Flat bar cast by the direct cooling process and cut off into square blanks has been used in Germany for piston stock with satisfactory results. The first operation, which consists of pressing the square blank into the circular die, induces a certain amount of radial flow, thus leaving the grain ideally orientated for the next operation. Previous working of the stock is not necessary or desirable, as it is before hammer-forging when the rate of deformation may be much too high to permit the metal being worked uniformly.

Cast stock has the additional advantages of being much cheaper than wrought bar, and having a cross-section to be sawn through less than half the area of that of round bar.—Yours truly,

Berkeley Square, London, W.1. N. F. JAMES.

*The article to which our correspondent refers is published on page III in our last issue. It was contributed by Mr. E. B. Graham, Technical Director of Specialloid, Ltd., and not by Mr. Kimber, whose name was given in error.—EDITOR.

British Cast-Iron Research Association

Annual General Meeting

THE twenty-fourth annual general meeting of the above Association was held in London, on Decem- 6, at which the balance-sheet, and reports of the Council were presented for the year ending June 30, 1944. The period under review terminated a five-year period for which the Association had grant arrangements with the Department of Scientific and Industrial Research. In normal circumstances, negotiations for the succeeding period would have been opened earlier in the year, but the pre-occupation of both the industry and the Association with matters arising from the war, induced the Council to ask for an extension of the existing arrangements for one year. This has been agreed to on the understanding that proposals for the next period would be presented.

This Association is performing a very great service to the engineering industry and to the foundry industry in particular; indeed, it is largely due to its initial work that the latter industry was given that impetus necessary to recover from the depression of the last war, from which the engineering industries have benefited in being supplied with castings possessing better physical properties and increased reliability than were then available. Since those earlier days the Association has made itself indispensable to industry in general and its contribution to the demands of the Services during the present war has been on a very high level, and there is sufficient evidence that it is being maintained.

It is noteworthy that, in the range of high-duty cast irons, work on the acicular irons has been continued and optimum compositions for this complex system worked out. Some information has been obtained on mechanical properties at elevated temperatures; one major section of this work is to be completed by determining a wide range of engineering properties on commercially made material. The collection of data on mechanical properties in relation to design continues. Work on the formation of graphite has been pursued with vigour. Work has been carried out on the partial substitution of linseed oil by petroleum extracts for core mixture and a report has been issued.

The Development Department continues to do excellent work in bridging the gap between research and practice. It continues to assist members on foundry problems and difficulties and on the application of laboratory results to practice. During the past three years the number of inquiries dealt with from members has averaged 1,250 per annum. This work is obviously of great service in building up the research and development programme, as well as forming a very desirable contact between the staff of the Association and members.

The Utilisation of Engineering Constructional Steels

By E. Simister, B.Sc., Ph.D.

(*Metallurgical Department, Kirkstall Forge, Ltd.*)

Significant metallurgical developments have been made in recent years in the production and utilisation of engineering constructional steels. War-time requirements have necessitated the utmost conservation of steel and all steel-making material, involving a rather drastic conversion to planned economy. Metallurgical progress has facilitated rationalistion of steel usage, the advantages of which may ensure the retention of its principles, under more normal conditions, for economic reasons alone.

THE description "engineering constructional steels" is intended to cover the carbon and alloy steels used in the production of machine details in all branches of engineering construction. As a class they can be distinguished from the low-carbon or low-alloy structural steels used by the civil engineer and shipbuilder in the form of plates and rolled sections. The constructional steels, products of the acid and basic open-hearth and electric furnaces, are available to the ordinary user in the form of bars, forgings or stampings, and cover a tensile range of from 30 to 100 tons per sq. in. In the widest sense the above description includes the high alloy and special purpose steels which derive characteristic properties from a relatively large alloy content, but for the purposes of the present discussion it is proposed to restrict consideration to those steels having a service performance governed principally by their mechanical properties and in which the alloy content does not exceed a total of about 5%. This class provides the high-duty steels for exacting service in aero-engine and automotive construction as well as machine-tool and general machinery production.

In recent years there have been significant metallurgical developments in the production and utilisation of these steels. The main trend has been in the direction of making the most economical and efficient use of material, although it must be admitted that this tendency has not always been readily discernible. With the war-time requirements of the Services creating an urgent need for the utmost conservation of steel and all steel-making material, mere tendencies were not sufficient and there had to be a rather drastic conversion to a planned economy.

Specifications

Probably the most important change which has taken place and which deeply concerns both the steel producer and user is the establishment of Ministry control over steel specifications. The pre-war purchaser of steel could always make his orders in accordance with the specified requirements of the design department. These requirements might be in line with existing standard specifications, but if the design department wished to assert itself it could always evolve a set of private specifications. Acceptance tests would be specified which so far as judging the suitability of the material for the intended purpose was concerned, were practically worthless.

Out of fairness to our engineer friends, let us admit that in many cases standard specifications were little better. Some of these had been drawn up to meet special circumstances and had been allowed to continue when the circumstances no longer existed, so that even official lists sometimes showed unnecessary duplication and there were some typical museum pieces. So far as specifications were concerned the "mass-effect" was largely non-existent. The engineer had heard of the term, but was probably half inclined to regard it as some metallurgical fad, and in any case 3½% of nickel could always be relied upon to deal with it. Evidently a good deal of guess-work, sometimes perhaps in the guise of experience, was entering into the selection of steel by specification.

It has been estimated that up to the early days of the war the industry had some 2,000 separate steel specifications to face, an extremely complicated position, which could only result in confusion to the supplier with no benefit to the consumer. In fact, the consumer who chose to work to his own particular non-standard specification was likely to be at a distinct disadvantage owing to increase in cost as well as possible hindrance to supply. Conditions in which the best use was not being made of available material were unfortunate to say the least, even in peace-time in a competitive world, but in time of total war such a position was untenable, and a radical change in outlook became essential.

The En Schedule

The British Standard War Emergency Schedule 970, introduced in 1941 and embodying the work of the Technical Advisory Committee of the Special and Alloy Steels Committee, represented a necessary reform in British steel specifications. The provisions of this schedule of wrought steels for general engineering purposes are now fairly well known, and the "En" steels which were brought into being are everyday acquaintances. A revised issue of the schedule was made in 1942, and there have since been additions and amendments.

The aim of the En series has been twofold. It was essential in the first place to secure the utmost conservation of alloying elements, and at the same time specifications had to be simplified and reduced in number. Rationalisation was obviously necessary if the supply position was to be adequate to meet the enormous demands of the services and industry. The new schedule listed fifty-eight steels of types regarded as sufficient to meet general needs and which could be broadly divided into the following groups :—Carbon steels ; low and medium alloy steels ; stainless and special steels ; case-hardening steels ; nitriding steels.

TABLE I.—TENSILE RANGES FOR EN STEELS HEAT-TREATED IN VARIOUS RULING SECTIONS.

U.T.S. Tons/ Sq. In.	LIMITING RULING SECTION				
	¾ in.	1½ in.	2½ in.	4 in.	6 in.
40/50			En 12. "40" carbon steel.	En 14. Carbon-manganese.	En 15. Carbon-manganese (Higher Tensile).
45/55			En 14. Carbon-manganese. En 15. Carbon-Manganese (Higher Tensile).	En 18. 1% chromium.	En 16. Manganese-molybdenum. En 17. Manganese-molybdenum (Higher molybdenum). En 19. 1% chromium-molybdenum. En 100. Low alloy. En 110. Low nickel-chromium-molybdenum.
50/60	En 10. "55" carbon steel. En 15. Carbon-manganese (Higher Tensile).	En 10. "55" carbon steel. En 15. Carbon-manganese (Higher Tensile).	En 18. 1% chromium.	En 16. Manganese-molybdenum. En 19. 1% chromium-molybdenum. En 100. Low alloy. En 110. Low nickel-chromium-molybdenum.	En 17. Manganese-molybdenum (Higher molybdenum). En 24. 1½% nickel-chromium-molybdenum.
55/65	En 10. "55" carbon steel. En 18. 1% chromium.	En 10. "55" carbon steel. En 18. 1% chromium.	En 16. Manganese-molybdenum. En 100. Low alloy.	En 17. Manganese-molybdenum (Higher molybdenum). En 19. 1% chromium-molybdenum. En 110. Low nickel-chromium-molybdenum.	En 24. 1½% nickel-chromium molybdenum. En 25. 2½% nickel-chromium molybdenum. (Med carbon).
60/70	En 16. Manganese-molybdenum. En 100. Low alloy.	En 16. Manganese-molybdenum. En 100. Low alloy.	En 17. Manganese-molybdenum (Higher molydenum). En 19. 1% chromium-molybdenum. En 110. Low nickel-chromium-molybdenum.	En 24. 1½% nickel-chromium molybdenum.	En 25. 2½% nickel-chromium-molybdenum (Med-carbon). En 26. 2½% nickel-chromium-molybdenum (High carbon).
65/75	En 16. Manganese-molybdenum.	En 17. Manganese-molybdenum (Higher molybdenum). En 19. 1% chromium-molybdenum. En 100. Low alloy. En 110. Low nickel-chromium-molybdenum.	En 24. 1½% nickel-chromium-molybdenum.	En 25. 2½% nickel-chromium-molybdenum (Med. carbon). En 26. 2½% nickel-chromium-molybdenum (High carbon).	En 25. 2½% nickel-chromium molybdenum (Med-carbon). En 26. 2½% nickel-chromium molybdenum (High carbon).
70/80	En 19. 1% chromium-molybdenum.	En 19. 1% chromium-molybdenum. En 24. 1½% nickel-chromium-molybdenum. En 110. Low nickel-chromium-molybdenum.	En 25. 2½% nickel-chromium-molybdenum (Med. carbon).	En 25. 2½% nickel-chromium. molybdenum (Med. carbon).	En 26. 2½% nickel-chromium-molybdenum (High carbon).
75/85 80/90	En 24. 1½% nickel-chromium molybdenum.	En 24. 1½% nickel-chromium-molybdenum.	En 25. 2½% nickel-chromium-molybdenum (Med. carbon).	En 26. 2½% nickel-chromium-molybdenum (High carbon).	En 26. 2½% nickel-chromium molybdenum (High carbon.)
100 min.	En 24. 1½% nickel-chromium molybdenum.	En 24. 1½% nickel-chromium-molybdenum.	En 25. 2½% nickel-chromium-molybdenum (Med. carbon).	En 26. 2½% nickel-chromium-molybdenum (High carbon).	En 30. 4½% nickel-chromium molybdenum.

For reasons of alloy economy, these have been divided into "permitted" and "non-permitted" steels, so restricting as far as possible the use of the more highly alloyed machine steels, such as the 3% and 3½% nickel and 3% nickel-chrome direct hardening and 5% nickel case-hardening steels. It has been directed that of the alloy steels only those in the group of 36 "permitted" grades can normally be used. The "non-permitted" steels are to be manufactured only in special circumstances and subject to the sanction of the Iron and Steel Control.

There has been a general upgrading of the carbon and the lower alloy steels, so that the alloy content of the permitted steels is usually lower than had previously been thought necessary for given mechanical properties. The familiar nickel and nickel-chromes are replaced by such compositions as manganese-molybdenum, chrome-molybdenum, and where nickel is permitted it is kept down to 1½ or 2½%. Many users felt "at home" with the older steels, and the substitute steels appeared as unfamiliar grades, greeted, not unnaturally perhaps, with certain doubts and suspicions. Unfortunately, the word "substitute" was apt to suggest inferiority rather than the intended equivalence. In fact, of course, the alternatives were not new steels, but had been in frequent use before their appearance in official specifications.

In 1943 two other steels were added to the specifications. These are En 100, described as a low alloy steel, and meeting the mechanical test requirements of the manganese-molybdenum steel En 16, and En 110, a low nickel-chromium-molybdenum steel which meets the mechanical test requirements of the manganese-molybdenum steels En 16 and En 17 and the chromium-molybdenum steel En 19.

The En 100 and En 110 types have compositions adjusted to make the most efficient use of the accumulations of alloy steel scrap and are likely to continue in perhaps more extensive use for some time.

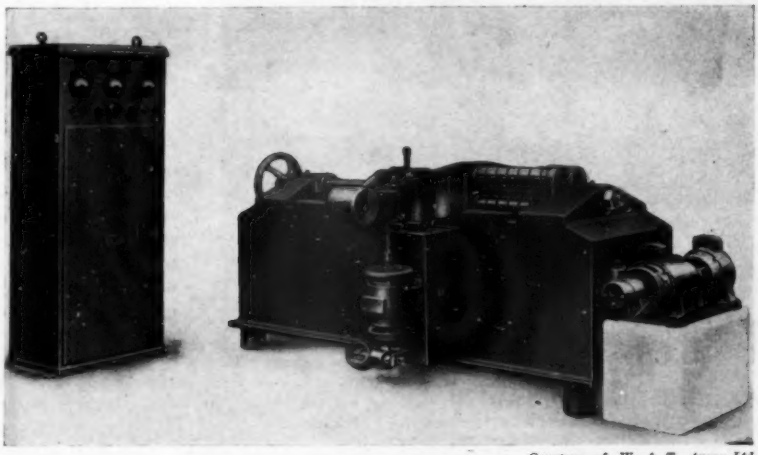
The Ruling Section

The most important feature of the En schedule is certainly the recognition of the over-riding influence of the mass-effect in response to heat-treatment. Although it has long been understood in a general manner that for equivalent mechanical properties the alloy content of steel must of necessity be increased as the mass or thickness of the section under heat-treatment

increased, it was not sufficiently appreciated, or at least practised that the reverse also applied and that reduced alloy contents would give equivalent properties in smaller sections. There always has been an inclination to associate particular ranges of mechanical properties with certain compositions, regardless of the mass involved. For example, the aircraft steel specification 4 S 11, a 3% nickel-chromium composition, was always designated as a 55/65 ton nickel-chrome steel, and the engineer might therefore be excused for specifying this steel for any application requiring a 55/65 ton alloy steel without consideration as to the mass. The 4 S 11 analysis will certainly give 55/65 tons in thicknesses up to 6 in., but how much alloy content will have been literally wasted in small sectioned work as a result of this and similar misapplications.

To eliminate the chances of precious alloying elements being wasted in this manner, and to assist the development of maximum properties in the heat-treated condition, the En steels for heat-treatment were issued with tables showing the mechanical properties to be obtained by heat-treatment of the particular steel within given limiting ruling sections.

By consulting the tables, the designer is enabled to select a steel which in the required mass or section will permit of the desired mechanical properties being obtained, and it is implied that the steel selected shall have the lowest alloy content possible. Table I has been compiled from data given in the En schedule, and indicates the class of steels which are available for heat-treatment to the various tensile ranges in ruling sections from $\frac{7}{8}$ in. to 6 in., 6 in. being the highest sectional limit intended to be covered by the En series.



Courtesy of W. & T. Avery Ltd.

Fig. 1.—"Pulsator" Fatigue Testing Machine for dynamic testing of full-sized components under various combinations of alternating and static loading.

Selection for Service

The selection of a steel must be based on many considerations. Apart from the general mechanical strength requirements, there may be special service requirements demanding, for example, wear resistance, or certain properties at abnormal temperatures. Fabrication characteristics, such as weldability, forgeability, machinability or heat-treatment considerations are also of great importance. In cases where special properties are dependent upon a particular composition, substitution by alternative grades is not always possible, but where mechanical strength is the governing factor in service there may be several steels from which to choose. By following the precepts of the En schedule the ultimate choice would, of course, be the steel carrying the minimum alloy content sufficient to ensure the desired strength. Commercial factors, such as cost and availability, will obviously play a big part in influencing selection, and there will always be a large element of personal preference.

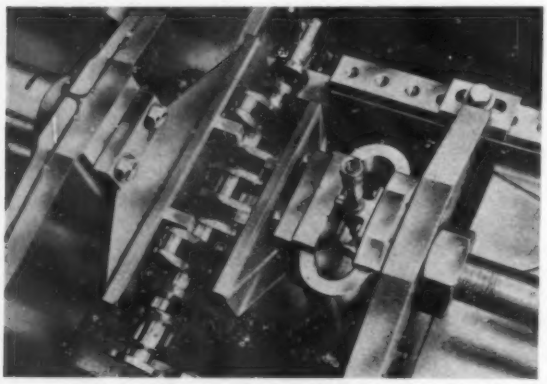
Reverting to the selection of steels on the basis of mechanical strength requirements, the assessment of the suitability depends principally upon the mechanical properties as usually determined by the tensile and impact tests. These tests are necessary in order to establish that the properties of the steel are in line with specification requirements, and the supplier cannot expect to be freed of his obligations in this respect. As consumers, however, we may on some occasions be acting inadvisedly if we were not prepared to be slightly indulgent. For the emergency period the En schedule has permitted certain relaxations in the mechanical tests and to further facilitate supply, a company's approved metallurgist has been empowered to authorise the use of material somewhat outside the limit of specified analysis.

It is evident that inspection as a whole should be applied intelligently and with sound discretion based on a knowledge of the intended application. It is an unfortunate fact that too rigid inspection has not infrequently resulted in the rejection and scrapping of much valuable material which could have fulfilled its purpose in a completely satisfactory manner. As it would be a practical impossibility to cover every application of steel by a separate specification, it becomes important that those responsible for inspection should have a close and accurate appreciation of the essential requirements in any specific application. Dependability is a prime service requirement, but hard experience has shown many engineers that this is not always to be secured by inflexible adherence to commonly accepted standards.

The Impact Test

There is probably no part of standard testing procedure which is associated with so much controversy as the Izod impact test. The impact value is usually regarded as a measure of the "toughness" or perhaps more descriptively the "notch-toughness" of the steel. In actual fact, the test does not measure any fundamental property of the steel, but only the energy required to break the notched sample under the specified conditions. If we vary these closely standardised conditions by, say, altering the shape of the notch, we find that the energy absorption is influenced considerably. The Izod impact

strength represented as so many foot-pounds is practically useless to the engineer as a basis for design, and to every argument which may be advanced in favour of high impact values the metallurgist can reply with numerous instances of exacting service conditions faithfully met by material which would give a very poor account of itself in the Izod machine. A high Izod value should no more be regarded as a guarantee of fitness for service than a low Izod value necessarily an indication of complete unsuitability.



Courtesy of W. & T. Avery Ltd.

Fig. 2.—Crankshaft under alternating bend test in "Pulsator" Fatigue Testing Machine.

The question might very well be asked, "Why, then, specify an Izod test if impact strength is so useless?" One answer to this could be to the effect that the engineer has not the courage of the metallurgist's convictions. A further reason should, however, be admitted, for despite many shortcomings of the test respecting the performance of a component in service, it nevertheless forms a useful criterion of satisfactory treatment and general soundness of the steel, and tends to emphasise conditions which may not be readily revealed by other methods of testing. The test should certainly be retained, but owing to its empirical nature the most careful judgment must be exercised in assessing steel on the basis of impact values, which should always be considered in conjunction with other known properties and operating conditions.

Endurance

Earlier mention has been made of dependability as the prime service requirement. To what extent we can rely upon the usual tests for constructional steel ensuring 100% reliability must depend on the operating conditions which the steel will have to withstand. If the steel is only to be subject to continuous and steady loading the working stresses will be known accurately, so that the necessary rigidity and permanence of dimensions can be readily secured. In many applications where constructional steels are used, however, the component is subjected to dynamic stressing, perhaps of a complex nature, with a possibility of unpredictable overloading or shock conditions also. The possible result of such conditions is only too well known to the engineering metallurgist, the most insidious of all metal failures, which is fatigue.

The influence of alternating stresses on metals concerns all manufacturers of components for dynamic service, whether for aero-engines or roller-skates, as fatigue recognises no social boundaries; the high-tensile alloy steel is just as likely to fall victim as the humble carbon steel, perhaps more so in some cases.

Precision laboratory testing shows that the endurance or fatigue limit—i.e., the highest surface stress which can be withstood for an indefinite number of cycles is only 50% of the ultimate tensile strength of the material. But these are tests on carefully prepared and smoothly polished specimens; in practice we are concerned with steel in all shapes and sizes and degrees of surface finish, and must not be surprised to find the endurance limit of a machined component down to about 10% of the ultimate tensile strength of the steel.

The effect of notches and surface irregularities of all types in functioning as stress raisers and so reducing fatigue strength has been demonstrated to the engineer on innumerable occasions, and metallurgists the world over have assiduously preached the doctrine of "the better the surface, the better the service." Splines, sharp corners, keyways, screw-threads, oil-holes and tool marks are abominations, and must be avoided wherever possible at points of maximum stress. Features of design and surface finish certainly have a far greater influence on the endurance of a component than any considerations regarding the metallurgical soundness of the material. Redesign of a part to improve mass-distribution will frequently result in greater benefit to endurance than any change in the steel.

There is no static test which can serve as a reliable guide to the endurance of a machine part in any given application, and small-scale fatigue specimens are not to be expected to yield much useful information as to the life of a component which will be of an entirely different shape, and operating perhaps under very different conditions. Information of much value to the designer may be obtained from tests on actual full-size components under conditions which simulate as far as possible the conditions to be encountered in service, but enabling at the same time standardisation and control. One type of machine which has been developed to carry out dynamic tests on full-scale details is illustrated. The results of full-size tests require careful interpretation, but from the results of a well-planned series it should be possible to arrive at definite conclusions which will assist in the choice of a steel, its optimum treatment, and the correct design to ensure maximum reliability in service.

Machinability

In discussing the selection of steels, mention was made of fabrication characteristics, and so far as constructional steels are concerned the most important of these is machinability. Mass production methods demand steel of consistently good machinability, and a certain amount of attention has been devoted recently, to determining the various factors which influence machining quality. Machinability is a very broad term, taking in such considerations as tool life and performance, rate of metal removal, surface quality, chip form and dimensional accuracy.

It is frequently said that machinability is difficult to appraise, and this is true for any attempt performed outside the machine-shop. Without a doubt, the most searching machinability test that could ever be devised

requires only a multi-spindle auto. and a piece-rate operator.

Every machinist experiences spells of difficult cutting at some time or other, and makes his periodic appeal to the metallurgist to do something about it, but by the time the metallurgist is called in there is often very little he can do, so far at any rate as the steel is concerned. The steel has already been melted, cast, rolled, forged and heat-treated. It might be possible to go back on the heat-treatment, but that only rarely solves the machinist's trouble.

Machinability starts in the steel-melting furnace, and has to run the gauntlet of the casting pit, the residue, if any, being the responsibility of the roller, forger and heat-treater. In the melting shop the steel receives its permanent non-metallic inclusion content. If this is mainly in the form of soft sulphide-silicates the machinist may have little cause for complaint, but if, on the other hand, it is hard, angular clusters of silicates and oxides and sub-microscopic specks of alumina, he is likely to be very busy dealing with rapidly worn-out tools. During the solidification of the steel in the ingot mould there is always a certain amount of dendritic segregation, but with the higher manganese steels this may be very marked, so giving a distinctly banded structure. The uneven distribution of the alloy content in this structure results in hard martensitic bands which have a very deleterious effect on machinability. This attribute is one of the disadvantages of the manganese-molybdenum steels because the structure once formed from the rolled ingot is very persistent, and cannot be eliminated by any usual heat-treatment.

It would be as well also to draw the machinist's attention to other factors which come into the general problem of machinability ; cutting speeds, tool angles, cutting fluids and machine-tool construction. Perhaps the part played by the machine-tool itself in affecting machining quality is not sufficiently well appreciated. Balance, rigidity and absorption of vibration are essential for the elimination of chatter, which can be as responsible for damage to tools as any metallurgical feature in the steel being cut.

A most important development in the metallurgy of the constructional steels is represented by the free-cutting types specially designed to have high machinability. The plain carbon free-cutting steels are well known in the resulphurised grades, and work is now being done on enhancing the machining properties of some of the higher tensile alloy steels. Lead additions are being used for this purpose, and tests recently reported on leaded alloy steels have yielded important information. The function of the lead in influencing machinability is not yet clear, although it has been suggested that the effect may be associated with the embrittlement which some of these lead-bearing steels appear to undergo at slightly raised temperatures.

Cold-drawing has a valuable effect in improving the machining qualities of steel, and the bright drawn steel bar represents in fact one of the most important forms in which the constructional steels are available to the engineering industry. Without the modern heat-treated bright steel bar the high automatic production of many essentials for both peace and war would not be possible, and it will certainly have an important part to play in post-war production.

Metallurgical progress in the steel industry has enabled the production of a greatly improved article, but the final responsibility for the most efficient utilisation must rest with the consumer. It seems probable that even after the removal of strict control the lower alloy steels will continue to be widely used, and it would certainly be unfortunate if there was any distinct tendency to return to the old extravagances. Perhaps it is not unreasonable to suppose that the advantages of rationalisation of steel usage have been sufficiently well realised by now in more than one quarter to ensure the retention of its principles for economic reasons alone.

Advisory Bureau of Research

ALTHOUGH various societies and institutions exist to encourage interest in particular subjects, no individual body has attempted to encourage trained engineers, scientists or technicians to become specialists in any one field of the various sciences. By trained engineers, scientists and technicians is implied all those who have qualified by apprenticeship or examination for either university degrees or membership of the technical institutions. There are many such skilled and enthusiastic workers who would relish the opportunity to study some special subject to become acknowledged "authorities," and seek guidance in this direction. It is the intention of the Advisory Bureau for Research, which has formed a department to encourage advanced study and specialisation, to offer guidance in this matter.

Owing to the advanced matter with which the Bureau will deal, it is impossible for tuition to be given in the normally accepted manner, and it is accordingly intended to advise (i) as to the values of specialisation ; (ii) problems requiring attention ; (iii) sources of information ; (iv) means of co-ordinating this advanced matter either as a thesis for a university higher degree, as a published treatise, or as a technical paper to the professional institutions or Press, and to rendering other assistance necessary to help in the advanced study of any subject. The Bureau intends also to compile a roll of specialists from those persons who have published authoritative treatise and papers.

By its activities the Bureau hopes to encourage specialisation among engineers of all classes—foremen, draughtsmen, laboratory workers, designers, works' managers, etc. From the guidance given to them, it is hoped that they will publish original and interesting accounts of the many problems which arise in all spheres of industry.

It is particularly anxious to encourage university graduates to undertake specialist studies to compose theses suitable for higher degrees. An examination of this aspect of technical education reveals that many students would have liked to obtain such qualifications before leaving the university. It is not difficult for most graduates in industry to carry out the literary work necessary for such degrees, and the Bureau believes that it can offer such people very valuable services.

To carry out these enterprising tasks, the Bureau has obtained the assistance of eminent engineers, scientists and technicians, and will publish policy reports outlining the various aspects of specialisation and research in such a way that advanced study of some kind can be carried out by most people with ambition, independent of their previous education or present occupation. These policy reports are of a confidential nature. Details are obtainable from the Director of Studies, 70, Victoria Street, London, S.W. 1.

Developments in the Production and Technology of Magnesium and its Alloys

By F. A. Fox, M.Sc., and G. Goddard, M.Eng.

In this article consideration is given to the main developments in magnesium technology during 1944, both in this country and abroad.

Extraction Process Development

THE year 1944 has seen great activity in the various magnesium production plants of which the information is available. As has been usual in the past, little concerning the sustained production of magnesium in the United Kingdom and in the Empire has been published, and there is no recent information concerning German and Japanese production. However, it is possible to state information concerning production in the U.S.A.

During the year 1944 the total American productivity probably reached its peak,[1] and after about the April of this year a certain amount of production cutting began, on the instructions of the U.S. Government (W.P.B.).[2-9] The total annual output rate achieved at the peak was, as far as can be ascertained, about 235,000 long tons. As the U.S. Government was in the position of having an excess of magnesium production capacity available, the question of what plants' productive capacity should be cut back was, no doubt, a problem, and must have involved careful weighing of the efficiencies of the various processes used in the U.S.A. from the point of view of total effort as well as in terms of cents per pound.

TABLE I.

RATED MAXIMUM PRODUCTION CAPACITIES OF GOVERNMENT-OWNED MAGNESIUM PLANTS IN THE U.S.A.

Process.	Company and Location.	Rated Annual Capacity, Lb./Annum.	Production Cut-backs (Up to Sept., 1944).
			%
Magnesium ..... Elektron (Electrolytic).	Basic Magnesium Inc. ..... Las Vegas, Nev.	112,000,000	100
Dow (Electrolytic)	Dow Magnesium Corporation, Velasco, Tex.	72,000,000	50
	Dow Magnesium Corporation, Marysville, Mich.	72,000,000	—
	Diamond Magnesium Corporation, Painesville, Ohio.	36,000,000	—
	International Minerals and Chemicals Corp., Austin, Tex.	24,000,000	100
Mathieson (Electrolytic).	Mathieson Alkali Works Inc., Lake Charles, La.	54,000,000	100
Carbothermic	Permanente, Cal.	24,000,000	50
Ferrosilicon	Ford Motor Co., Dearborn, Mich.	40,000,000	100
	Permanente Metals Corp., Lathrop, Cal.	20,000,000	100
	New England Lime Co., Canaan, Conn.	10,000,000	—
	Magnesium Reduction Co., Luckey, Ohio.	10,000,000	—
	Amco Magnesium Corp., Wingdale, N.Y.	10,000,000	100
	Electro. Metallurgical Corp., Spokane, Wash.	48,000,000	50

Peak production rate about 235,000 long tons per annum.
Estimated production rate following cut-backs about 75,000 long tons per annum.

In col. 1 is given a table of the various processes used by different American Government plants, together with their rated maximum production capacities.[10] Actual production figures for the different plants have not been publicised; it is known, however,[10] that in March, 1944, of the 13 plants given in Table I only six were producing above the rated capacity (including B.M.I. and plants operating the Dow process), two were operating or a near capacity; five were still below capacity.

Although the M.E.L. electrolytic process has been the one which has been responsible for the great bulk of the British production, and which, as can be seen from the above figures, has also figured very largely in the American output, much interest has been displayed in other direct processes, since their energy expenditure per pound of magnesium are less—if the process can be made to work. One important difficulty of some direct processes is in the conversion into a usable product of the finely divided magnesium powder which is produced. This difficulty has been reflected in a patent[11] which has been made public during the year, in which it is proposed to use directly the product from a thermal reduction plant (a mixture of magnesium powder and oil) as an incendiary bomb filling.

Parallel with the interest which is now being taken in the production of aluminium from clay, there has also been close examination of the possibilities of producing magnesium from asbestos. In a publication[12] on this subject, reference is made to a large "tailings" deposit of asbestos for which it is claimed a process has been worked out for extraction of the magnesium content. Beyond this there have been interesting publications on the direct production of magnesium, one in particular[13] describing plant details and constructional material difficulties particularly connected with steel retort problems.

A review[14] of the operation of the world's largest electrolytic magnesium plant (Basic Magnesium Inc.) has also been given in which this enormous 56,000-ton capacity plant, located in the Nevada Desert, is described. Some idea of the magnitude of this M.E.L. type plant can be obtained from the quantities of bus-bars used in the electrolysis—4,000 tons of bus-bars were required, of which 2,000 tons were of silver.

Table I gives details of the projected U.S. Government cut-backs, which are designed to reduce the total output of virgin magnesium to about 75,000 long tons per annum.[8] This means, in effect, that by the end of 1944 magnesium production in the U.S.A. will be reduced by about 70%, as compared with the peak production at the beginning of the year; it will still exceed the 1939 U.S.[9] production level by about 2,500%.

Fabrication Process Development

Data has not been made available in this country about the distribution of magnesium output into various semi-fabricated forms, but this data has been made available in the U.S.A. and the W.P.B.'s statement[15] is given in Table II for 1942-1943.

TABLE II.
U.S. PRODUCTION, 1942 AND 1943: ANALYSIS OF FABRICATED MAGNESIUM PRODUCTS.

Fabricated Products.	1942 Short Tons.	1943 Short Tons.
Castings—		
Sand	16,146	29,561
Gravity die-cast (*a*)	682	1,989
Pressure die-cast	652	1,433
Wrought Products—		
Forgings	21	113
Extrusions (*b*)	208	514
Sheet, strip, etc.	439	840

(*a*) Excluding cast sticks for powder manufacture and castings for incendiary bomb bodies.
(*b*) Excluding extruded sticks, rolling slabs and forging stock.

It is to be expected that generally similar ratios will pertain for this country, although it is possible that the proportion of material converted into pressure die-castings in this country will not be as great as in the U.S.A. It is to be noted that the production of forgings in 1943, while still being small, has jumped in a way which is out of proportion to the total increase in availability of magnesium. It is to be observed that the ratio of wrought to cast material for magnesium alloys is about 1–30; a similar U.S. estimated figure for aluminium alloys is 5–1.[16] For the U.K. it is possible that the 1–30 ratio for magnesium alloys would be modified, and that the figure might be nearer 1–20.

Mechanical Properties.—As far as can be ascertained, no material alterations in the expected mechanical properties of the commercial alloys has taken place during the year. This standard data, therefore, can be obtained by reference to other literature.[17]

Casting.—No radical improvements are known to have taken place in the casting field during the year.

It is probable that the use of close inspectional methods has steadily improved, particularly in the U.S.A., arising from the need for careful control of the quality of highly stressed aircraft castings, and to cut down high scrap percentages.

Attention has also been devoted to the subject of enabling relatively poor castings to pass high inspectional standards, particularly from the point of view of porosity. Papers[18, 19, 20] have been published dealing with rectification processes for eliminating the effects of porosity in castings. These describe the use of tung oil and styrene-co-polymer. Connected with this subject is an examination of the theoretical background to the formation of the microporosity which some magnesium alloys tend to display. Much work has been in progress in this country on this subject during the past year, and it has also been examined in a U.S.A. publication by Eastwood,[21] who seems to agree in general with earlier expressed British views to the effect that microporosity is essentially a local shrinkage phenomenon and that the real problem is one of control of temperature gradients and solidification sequences.

A paper by Nelson[22] describes the use of a reverberatory furnace (which is unorthodox practice) for the production of magnesium alloy ingot, even of low iron content if desired; although this development does not come into the field of ordinary casting as such, it is possible that it may point the way to future foundry application. Nelson also gives a description of some American fluxes and fluxing procedures which are rather different from, and possibly less effective than, those in use in the U.K.

In contrast with this, a paper by Hirst[23] gives details of standard British practice involving large melting crucibles and the necessary safety precautions. As far as British fluxing practice is concerned, a full description of the methods and reasons underlying them is given by Emley.[24] Some work has been in progress in the laboratories of Magnesium Elektron, Ltd., during the year on the mechanism of the superheating process as applied to magnesium alloys in the foundry, and although no general solution of this complex problem has been arrived at certain interesting points have come out. In particular, full confirmation has been obtained of earlier suggestions to the effect that it is quite possible to "over-superheat" magnesium alloys, and a short time of exposure to temperatures of the order of 950° C. will cause a grain-coarsening effect to set in; it has also been shown that superheated material has a characteristic microstructure.

It is scarcely necessary to make detailed reference to the very large number of papers which have appeared in the American technical press describing the various but, generally speaking, commonplace foundry techniques in different plants in the U.S.A.

Rolling.—The only published information of any interest on this subject in the U.K. has been that of Jones,[25] who describes the rolling characteristics of an alloy conforming to D.T.D. specification 118. He examines the rollability of this alloy from cast blank and from extruded slab, and concludes that there is little to choose between the workability of the two forms of material and in the properties of the end product. If anything, the advantage lies with the sheet derived from the cast material. This experimental work confirms the standard works practice established in this country some years ago. A recent paper by Stroup, Sager and West[26] gives mechanical properties for magnesium-aluminium alloys and magnesium-zinc alloys in the cold-rolled state and in the annealed state. This paper also relates sheet properties with compositions over the range aluminium 1–12% and zinc 0–5%. Their results, in general, in so far as they cover work which had previously been done, agree well with those of previous investigators. This paper also refers to development work which is apparently proceeding on the "cladding" of strong magnesium alloy sheet with pure magnesium. That is, apparently, a re-examination of a problem which has already received close consideration in this country, and, before the war, in Germany; the emphasis is here laid, however, on the possible good effects of cladding against stress corrosion of the strong sheet material.

Forging.—Little published information is available in connection with developments in forging. It is interesting to note the renewed interest which is being shown in the U.S.A. in the hammer forging of an alloy containing 5% tin, 3% aluminium. It will be recalled that this proprietary alloy (American Magnesium Corp. alloy AM65S) has been publicised for several years in American trade literature, which stressed its ease of fabrication by hammer forging.

Extrusion.—No published information is available concerning advances in the extrusion of magnesium. However, in June of this year, a reference was made in the technical press[27] to the effect that the Revere

Copper and Brass Inc. Co. are operating a very large extrusion plant at Halethorpe in the U.S.A. (the same company is also operating a large magnesium rolling mill at Baltimore).

Engineering Process Development

Welding.—As far as is known, the gas-welding process has dealt, in this country, with at least as large a tonnage of magnesium sheet this year as in previous war years, and it is possible that it has dealt with larger tonnages. The same is probably true of the U.S.A. In this country the Argonarc welding process has not yet been applied on a commercial scale, and the development of the Argonarc hand torch process seems to be slow. The development of mechanical applications of the Argonarc process is also continuing. It is understood that in the U.S.A. much use is made of the Heliarc torch in the repair of castings, and it is possible that this may prove to be the most successful application for this process which is somewhat "temperamental" when applied by hand to thin sheet—the earlier American claims were probably over-stated.

A useful paper[28] on jig construction in the gas-welding of magnesium alloy sheet has recently been published in the U.S.A., which carries much practical information on methods such as have been used in the U.K. for some years.

Several references[26, 29, 30, 31] have been made during the year to the spot-welding of magnesium alloys, but the application of this process is of small proportions in this country, and is believed not to be of much consequence in the U.S.A.

Sheet Working.—Although it is known that the working of magnesium alloy sheet has reached a high pitch of perfection in this country and that excellent work is being done, particularly in complex fuel tank construction, no information on sheet working has been made available in this country during the year. However, various U.S. publications have been made, some of them very useful. These include papers by Harvey and West,[32] Resos,[33] Stroup, Sager and West,[26] Winkler[31] and Nagy.[34] They deal with many aspects, including the application of the Guerin process to the forming of magnesium sheet and to development of the hot spinning of magnesium alloy sheet. Parabolic propeller cowls have been made by the spinning process, 16 in. deep × 24 in. base diameter. In Harvey and West's work they report that magnesium alloy sheet can be given a deep-drawing deformation equivalent to 60% reduction when the die temperature is at 315° C.

Machining.—A few general papers[35, 36] have appeared during the year on the machining of magnesium alloys; these have contained little that is new.

Protection.—Little of great importance has been published during the year on this subject. However, Bowens and Gilbertson[37] described the silver plating of magnesium alloys late in 1943. Presumably this was mainly for decorative purposes. Loose and De Long[38] have summarised American protection methods, and a British paper[39] describes at some length the part played by chromates in the protection of magnesium. Aside from this, there have been a very large number of publications in the U.S.A., but these contain nothing that is fresh. However, a paper by Simpson and Cutter[40] refers to the excellent results in terms of corrosion and abrasion resistance of an alkaline anodic bath treatment developed at Consolidated Vultee Aircraft Corporation.

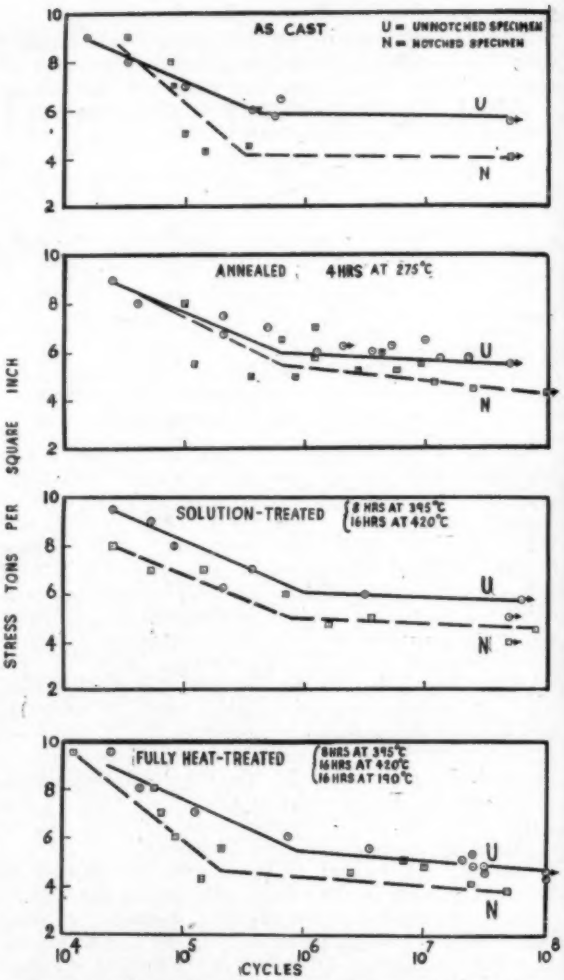


Fig. 1.—Wöhler fatigue test results on Elektron A8. Nominal composition: Al 8.0%, Zn 0.4%, Mn 0.3%, remainder Mg.

Research Developments

Properties of Alloys.—Much work on the properties of standard alloys has been done during the past twelve months in the laboratories of Magnesium Elektron, Ltd. This includes work on the fatigue characteristics of different alloys in the notched and in the unnotched states, and also the obtaining of impact data on magnesium alloys in different states of heat-treatment when tested in the notched and in the unnotched states. This, information will be published in due course, but Figs. 1 and 2 give an indication of the type of results being obtained. It will be seen that the shape of the S/N curve of the notched material is as favourable as is that of the unnotched. As far as the impact and slow bend properties shown in Fig. 2 are concerned, the favourable properties of solution-treated Elektron A 8 are evidently of interest. The reduction in the impact values from 15 ft.-lb. to about 4 ft.-lb. by the presence of the notch again underlines the necessity for the use of smooth contours in the design of magnesium alloy components. An interesting paper on the value of

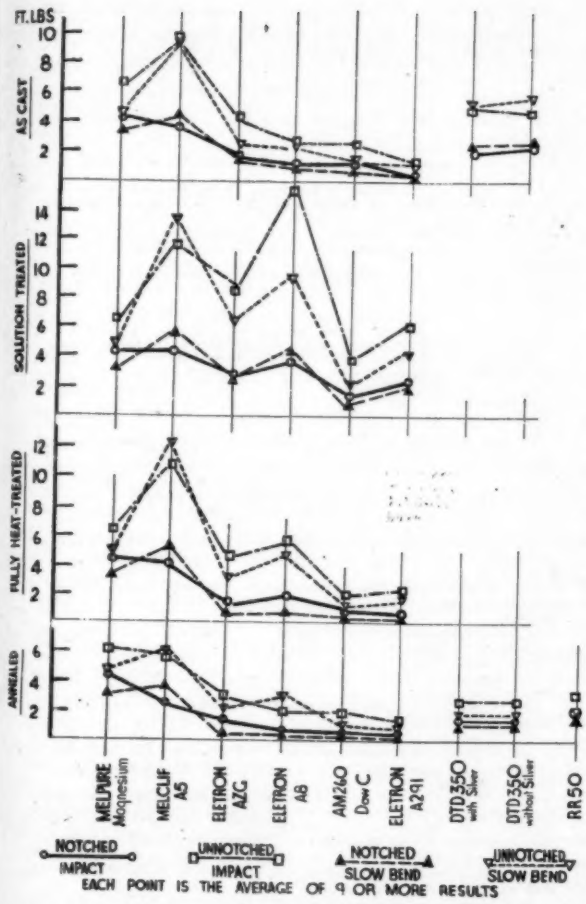


Fig. 2.—Notched and unnotched Hounsfield impact and slow bend test results for cast and heat-treated magnesium, magnesium-base alloys and one aluminium-base alloy.* Hounsfield/Izod impact conversion factor = ×I.

*NOMINAL COMPOSITION OF MATERIALS TESTED :—

Melpure Magnesium—Mg with impurities less than 0·3%.
Melclif A5—Mg + 5% Al, 0·4% Zn, 0·3% Mn.
Elektron AZG—Mg + 6% Al, 3% Zn, 0·3% Mn.
Elektron A8—Mg + 8% Al, 0·4% Zn, 0·3% Mn.
AM 260 (Dow C)—Mg + 9% Al, 2% Zn, 0·2% Mn.
DTD 350—Mg + 6% Sn, 3% Al, 0·3% Mn (DTD. 350, with silver carries 1% Ag).
RR. 50—Al + 1·3% Cu, 0·9% Ni, 0·1% Mg, 1·2% Fe, 2·25% Si + 0·18% Ti.

Young's Modulus in tension and in compression has been published by Dorn and Thomsen[41] who also show some hysteresis curves for magnesium alloys.

Structure.—A book entitled "Metallographie des Magnesiums und seiner technischen Legierungen," by Bulian and Fahrenhorst, has been translated by the technical staffs of F. A. Hughes and Magnesium Elektron, Ltd., and has been published by F. A. Hughes. This carries reproductions of 225 micrographs, and is a useful reference book on this subject.

A paper has been published during the year by Lardner[42] on the possibility of applying steel-quenching techniques to aluminium-containing magnesium alloys. This work showed that "interrupted quenched" structures and fully quenched and precipitated structures were equivalent, and were associated with similar mechanical properties. A paper by George[43] describes a possible system for standardising the description of magnesium alloy structures, so that magnesium alloys can be examined and reported on by relatively unskilled workers. A paper by Tarr and Mahoney[44] describes grain size standards for magnesium alloys, rather similar to that used in the steel industry, though it is not clear why it is necessary to deviate from normal methods which directly measure the grain diameters and express the answer in millimetres or inches.

Corrosion and Stress Corrosion.—Some work has been done on the corrosion resistance of low iron content magnesium alloys,[45] and this has shown that American work has overstressed the importance of low iron contents, and that at least for the cast alloys (the wrought alloys have not yet been systematically examined) provided there is sufficient manganese present to offset the harmful influence of a "normal" iron content (about 0·02%), the corrosion resistance of low iron alloys and of "ordinary" alloys is similar as judged by total immersion tests and also by atmospheric exposure tests. Another paper[46] gives some interesting results on the long-time atmospheric exposure of magnesium alloys, and shows that the corrosion losses after about five years' exposure to an industrial urban atmosphere are low as judged by tensile strength data before and after test.

No information has been published in this country on the influence of stress corrosion on magnesium alloys. One of the reasons for this is that the sheet alloy exclusively used in this country is that conforming to D.T.D. specification 118 (Elektron AM 503, a binary manganese containing alloy). This alloy in the annealed state as supplied in this country is

Fig. 3.—A group of magnesium alloy pressure die castings : interest in this process as applied to magnesium is increasing.

Fig. 4.—Magnesium alloy forging : a German engine mounting (half ring). Note the smooth section changes ; this is a good example of design appropriate to magnesium alloys. Reproduced approximately $\frac{1}{12}$th the actual size.

not prone to stress corrosion, and consequently this question is not an active problem here. In the U.S.A. higher strength aluminium-containing alloys are used, sometimes in the hard-rolled state. These alloys are prone to stress corrosion, being more so with increasing aluminium content.[26] Mathes[29] points out that one of the most important factors in stress corrosion considerations in the U.S.A. has been high residual stresses following on arc-welding operations. The subject of stress corrosion has been touched upon in various other American publications.

Strength at High Temperatures.—A considerable amount of work has gone on in this country on strength of magnesium alloys at elevated temperatures. So far, little information has been made public ; Fisher[47] has, however, surveyed the available published data.

Applications

In the U.K. the applicational picture has, as far as is known from published data, changed little during the past year ; apart from a few specific items, which are in any case connected with essential war work, the entire production of the country is still devoted to the aircraft and munitions industries, apart from the tonnage of metal placed into stock. As far as can be judged from the examination, from the point of view of widened application, of German aircraft parts, the general position appears to be little changed in Germany also.

In the U.S.A. the accumulation of a stock-pile of magnesium following "over production" is likely to affect the applicational picture to some considerable extent. The U.S. Government has already authorised the use of some magnesium for non-essential purposes,[48] and there is now evidence of a strong applications drive in the U.S.A.

A great many papers have appeared dealing with many aspects of magnesium alloy applications. Two papers by Goddard[49] and by Basch,[50] of British and American origin, discuss future prospects from the technical point of view, and a paper by Mathes[29] gives interesting information on the use of magnesium in American war planes. In this latter paper instances are given in which failure of magnesium alloy parts in the U.S.A. is attributable wholly to incorrect design. A paper by Sutton[51] gives interesting information on the use of magnesium alloys in some German aircraft.

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Metallurgical Progress in Tin

By John Ireland, M.C., B.Sc.
(*Director, Tin Research Institute.*)

The widespread search for, and tentative use of, substitutes and alternatives which scarcity enforces may well serve chiefly to bring out more clearly the advantages of previously established usage. This is apparently exemplified in such uses of tin as tinplate, solder and bronze, in which recent experience suggests that future progress will be the result of intelligent development of previously established practice.

THE metallurgical progress with which we are most familiar arises through experimentation which exploits the virtues of some novel process or material and eventually establishes its superiority to some previously accepted practice. In times of scarcity progress may often depend on the opposite principle. The widespread search for, and tentative use of, substitutes and alternatives which scarcity enforces may well serve chiefly to bring out more clearly the advantages of the previously established usage.

This is certainly exemplified in such uses of tin as tinplate, solder, and bronze, where recent experience suggests that there is less likelihood of progress by substitution than by intelligent development of previously established practices.

Since the beginning of 1942 the United Nations have been cut off from the rich tin fields of Malaya and the Dutch East Indies, and in consequence strenuous efforts have been made to reduce consumption without hampering the vast output of munitions and other products required by the fighting forces. Every tin-consuming industry in Britain and in the United States has turned the full force of its technical organisations to reduce consumption, and it is safe to say that no alternative and no expedient has been left untried, and continuous efforts have been made to get the best possible service from every pound of tin available.

Tinplate

About 40% of all tin is used for tinplate, and this field obviously presented the greatest opportunities for economy, although record quantities of canned foods have been required to feed the armed forces. American experience may in this case be taken as typical. The Can Manufacturers formed a technical committee, and the various steps taken were reported last June by Dr. R. H. Lueck.[1] Apart from regulations which eliminated many uses of tin deemed inessential in war-time, the first important economy took advantage of the improvement in the steel base which in recent years has become available. In America cold reduced steel strip has completely ousted the hot-rolled sheets on which the industry used to depend, and its use has permitted the normal coating thickness of tin to be reduced from 1·5 lb. or 1·35 lb. to 1·25 lb. per basis box without seriously affecting its performance as a container for many commodities.

The next step aimed at a more drastic economy. It was thought that lacquer could displace tin in certain cases. It was found, however, that corrosion developed rather quickly under the lacquer. To prevent this, the untinned steel was given a preliminary phosphatising treatment (bonderising) which provides considerable protection and increases the adherence of the lacquer. This type of package has proved serviceable for less exacting packs, such as golden syrup, and has been used for tobacco and for closures on glass jars, and is acceptable as a war-time expedient.

A considerable saving has also been effected by the use of bonderised and lacquered can ends, in combination with tinplate bodies, in cases where early failure would have occurred if the entire can had been made of the substitute material. This brings out an interesting feature of the mechanism of the corrosive processes that occur inside a food can. It is well known that tin stands considerably above iron in the electro-potential series, and under normal conditions when the tin-iron couple is exposed to a corrosive agent, the tin is unaffected while the iron is attacked. But conditions are far from "normal" inside a can. In particular, the supply of oxygen is severely limited, and after it has been absorbed in the first superficial attack on the tinplate walls, the conditions reverse, the tin becomes anodic, and thereafter acts as a corrosion inhibitor; it not only protects the steel by covering it, but also exerts a potential which prevents direct attack on exposed steel. This peculiar property of tin is an important factor in the success of the tinplate food can.

The next major effort at tin economy hinged on the development of thin electrolytic tin coatings. This process has the attraction of being continuous, and long lengths of steel strip can be run through the plating baths without the complication of handling the small separate sheets used in the older hot-tinning process. Some twenty large plants have been erected in America, and about half of them are operational, although the market has not yet absorbed more than a quarter of their combined capacity.

These plants were originally designed to produce coatings of 0·5 lb. per basis box. This drastically reduced coating has not found acceptance, and 0·75 lb. is now being made, and some quantity is to be utilised for packing milk products.

After two and a half years of strenuous efforts to reduce tin consumption, the position to-day is that more food than ever before is being packed in tin containers and the hot-dipped tinplate is still in substantial possession of the field.

A new and important contribution to improved performance of tinplate is the chemical filming rust-resisting process developed at the Tin Research Institute. This consists of a brief immersion of the tinplate, or the finished can, in a hot oxidising solution. This solution

1 R. H. Lueck and K. W. Brighton. "Metallic Substitutes for Hot-dipped Tinplate." *Industrial Engineering Chemistry*, June, 1944.

reacts superficially with the tin, and with the iron at the exposed pores, and produces an invisible film which imparts a greatly increased resistance to rusting (see Fig. 1). Some millions of cans have already been treated in this way, and a number of firms have arranged to adopt the process. If it could have been adopted earlier it would have greatly reduced the loss of tinned foods arising from the external corrosion and rusting inseparable from handling and storage in the field. It will certainly enhance the attractiveness and lengthen the shelf life of our post-war food cans.

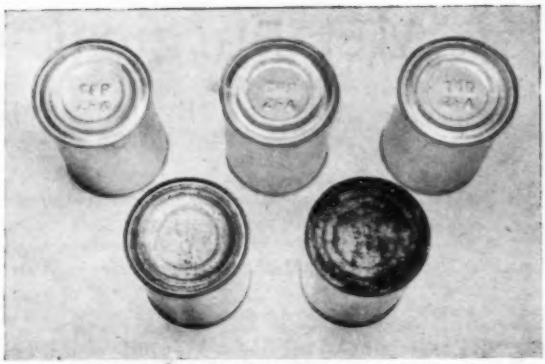


Fig. 1.—These five cans have been exposed outdoors. The three cans which had been rust-proofed remained bright, but the untreated tinplate cans became badly corroded.

Bronzes

Quite a lot of tin is used in the manufacture of bronze even in peace-time, and with the expansion of output of our shipyards, this has become a major field of consumption. No radical change in this field has emerged. Economies have been effected by a more careful grading of specifications and the choice of lower tin alloys for the less exacting tasks. It may have been surprising that silicon bronzes have not taken a larger share of the market. Their limitations were, however, fully understood even before the tin shortage developed.

CAST TIN BRONZES, ETC.

PHYSICAL PROPERTIES OF CHILL CAST STICKS CAST FROM REMELTED SCRAP.

As Made by the Tin Research Institute.							Specification Requirements of Comparable Alloys.		
Alloy.					Physical Properties.		Physical Properties.		Specification.
Sn.	Zn.	Pb.	P.	Ni.	Tensile, Tons/Sq. In.	Elongation, on 2 in.	Tensile, Tons/Sq. In.	Elongation, on 2 in.	
10	2	—	—	—	22–24	10–15	16	—	B.S. 382, 383, 282, etc.
10	—	—	0·5	—	24–28	10–20	16	1½–4	288
5	5	5	—	—	18–19	26–28	12	—	B.S.S. 808
5	—	20	—	1	15	15	8–10	—	—

There has been a useful recognition of the part lead may play in simplifying the production of pressure-tight bronze castings without material sacrifice of their strength and toughness. This has been brought out in a paper by F. Hudson,[2] which will facilitate a more judicious choice of alloys for certain purposes. From the point of view of post-war developments, the most important progress is marked by two papers by Dr. W. T. Pell-Walpole.[3] These describe an improved technique applicable particularly to the production of bronze ingots and sticks in metal moulds, and covering the melting and pouring and ingotting processes. It has long been recognised that the valuable qualities of malleable bronze increase with the tin content, but so too do the manufacturing difficulties. It has now been established that absorbed hydrogen is at the root of the trouble. This can be removed by melting under a suitable oxidising flux, but dissolved oxygen may then become troublesome. A balanced treatment is essential. A new flux has been devised and procedures worked out which enable the hydrogen to be oxidised and any metallic oxides fluxed off into the slag in one operation. A final deoxidation with phosphorus provides a gas-free alloy which can carry as much as 12% of tin without the formation of intractable δ particles. Gas-free bronze has, however, so considerable a shrinkage that special precautions are necessary. Very slow pouring is the answer. Methods and conditions have been worked out which give greatly improved physical properties, as will be seen in Table I.

The important quality of bronze cast in this way is, however, not the strength in the as-cast condition, but the fact that it can, after a few hours' anneal to absorb traces of the deltoid constituent, be extruded, hot-forged, or cold-worked to an extent not hitherto practicable. Figs. 2 and 3 are typical products. No new or special equipment is required, and the customary grades of tin and copper can be used. Commercial production has already got under way and large markets are anticipated for this new and interesting product.

Fig. 2.—Test pieces: made from 10% tin bronze extruded bars, cold rolled 70%, 74–75 tons tensile, 17·5% elongation.

Solders

One of the more striking metallurgical developments arising out of the shortage of tin has been the introduction of silver-lead and silver-lead-tin solders. The efforts made to economise the use of tin in solder are exemplified in the revised soft solder specifications issued by the British Standards Institution, B.S. 219 (1942) and its attached memoranda Nos. 1, 2 and 3. Their effect was to reduce immediately the number of grades of tin-lead solder in common use to five; and to direct attention to refinements of soldering technique, such as a more careful choice of the composition of solder used, greater care that the amount of solder used was adequate, more frequent use of thin sticks of solder, and for spot-soldering and other small work, the use of flux-cored soldering wire. Memorandum No. 2 gave much useful information on the properties of the lead-silver

2 Frank Hudson. "The Use of Leaded Gunmetal for the Production of Castings to Withstand Pressure." *Journal of the Institute of Metals*, 970, vol. 11.
3 W. T. Pell-Walpole. *Journal of the Institute of Metals*, 960 and 966, vol. 70.

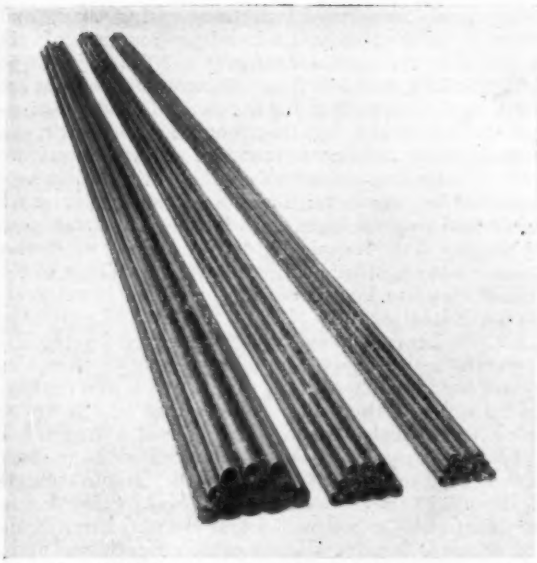


Fig. 3.—Cold-drawn tubes from 10% bronze, used for evaporation, condensers, etc.

solders and the lead-silver-tin solders known in Great Britain as Argent solders. The lead-silver solder immediately found application for the seam joints in can bodies. A stronger flux and a higher soldering temperature was required, but the necessary modifications were made on the automatic can making machines and satisfactory strong joints were obtained. The first objection from the canners' point of view was that the higher temperature damaged certain types of lacquer, but more serious drawbacks have since developed. It is found that the tin coating is partly removed during the soldering operation and a strip down the side of the can is unprotected and very rapidly corrodes. This makes such cans unsuitable for the rough usage and difficult storage conditions in the field. The unsightly and corrodible strip will not prove a selling point in peacetime, and it is likely that this substitution will be abandoned.

The broad feature of the Argent solders is that about 1 or 2% of silver can so increase the fluidity of the molten solder that as much as 10% tin content can be saved without loss of fluidity. This range of alloys was received as a welcome possible economy and has been very fully tried out. During the past two years practical experience of users has followed a very similar course in both the U.S.A. and the U.K. At first their undoubted metallurgical virtues were extolled. Then the disadvantages became more obvious, and their use has lapsed in many cases. This is due to the peculiar qualities demanded of soldered joints. These are essentially, ease and certainty of formation, at the lowest possible temperature. Although silver contributes substantially to the fluidity of molten lead-tin alloys, its contribution to the essential matter of joining two pieces of solid metal is much less, and it fails to justify its cost. Tin appears, in fact, to have a unique ability to wet the common engineering metals and to be the active and essential element in effecting a soft-soldered joint.

There is, however, another important factor in soldering—the selection of the proper flux. The ideal flux would be so active that it would clean the most difficult surface, and yet when the soldering operation has been performed the ideal flux residue should become completely non-corrosive. Such a flux has not yet been devised, but useful progress has been made in increasing the activity of resin without impairing its very valuable non-corrosive qualities. A number of activators, such as Fixanol, aniline hydrochloride, etc., are now accepted in the M.A.P. Specifications, and fluxes of this kind are obtainable through most of the usual trade channels.

Another step towards rapid and reliable soldering is the use of pretinning. Tinning by hot-dipping is an old established and widely used expedient, but developments in electro-tinning have greatly extended the applicability of this measure. The electro-tinning processes developed in the past six years must not be confused with the older electro-tinning processes which, although they could provide a coating of attractive brightness, could not apply a coating of sufficient thickness to provide, with certainty, an easily solderable surface. Two types of plating baths are now available, and their use is extending rapidly. Small parts are commonly plated in bulk, either basket-plating or barrel-plating being used. In the large scale manufacture of electrical instruments and equipment, whose performance depends on a multiplicity of soldered joints, the use of pretinning has effected almost revolutionary improvements.

Tinning Cast Iron

An interesting and permanently valuable advance in the art of tinning cast iron has arisen as one outcome of a purely war-time research. It was believed until recently

Fig. 4.—Machined cast iron tinned by the conventional method (actual size).

Fig. 5.—Similar piece of machined cast iron tinned by the new T.R.I. method (actual size).

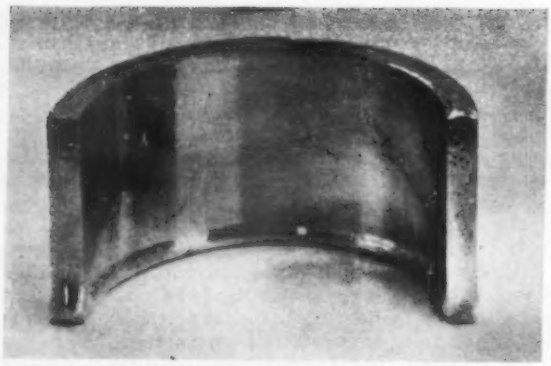


Fig. 6.—Machined cast iron bearing shell tinned by the new process (actual size).

that hot-dipped tin coatings on cast iron must inevitably be inferior, and that it was difficult to make a soldered joint, and not practicable to bond a white-metal bearing strongly to a cast-iron shell. A new process has been devised in the laboratories of the Tin Research Institute which eliminates the need for preliminary iron or copper-plating and which enables cast iron to take on a tin coating almost as successfully as does mild steel or copper. The past difficulties have arisen because cast iron is by no means a homogeneous material, and the pickling acids needed to remove the oxides do not attack graphite or silica. Indeed, thorough pickling results in the formation of a smear of graphite which is exceedingly difficult to remove, and which gives rise to very inferior tin coatings. The new process depends on the use of fused salts chosen to provide a bath of low melting point and satisfactory stability.

The success of the process may be judged from the point of view of general appearance and protection from corrosion, or from the bond strength to white metal. The first aspect may be judged from the accompanying photographs, Figs. 4, 5 and 6. The normal methods of tinning cast iron provide little or no adhesion to white metal, the new methods give adhesion values of 3 to 4 tons per sq. in. consistently.

From the engineer's point of view, the new process will permit considerable economies in design to be effected. The expensive grooves and dovetails previously needed can be dispensed with, and white-metal linings can be made thinner, while providing considerably better load-carrying capacity.

Bearing Alloy

Tin economy in bearings has not produced any obvious metallurgical developments. The requirements of bearings vary widely, and many alloys continue to be used. The present use of tin in bearings is controlled in Great Britain by Ministry of Supply Circular Ref. P.B. 1, March, 1942. White-metal bearings are classified into four groups. High speed with fluctuating load, high speed with steady load, low speed with fluctuating load, and lowspeed with steady load. The amount of tin permitted in the respective classes is 80 to 92%, 68 to 72%, 7 to 12%, and 0 to 3%. The recommendations are based on the belief that for the more difficult bearings high tin is essential, but that progressively less tin can be used in less exacting circumstances. The experience of the Tin Control confirms that this is the widely held opinion of bearing users. But the absence of figures for speeds and loading in such a document coupled with the paucity of the technical literature and the conflicting claims made for other bearing alloys, is evidence of the lack of accurate knowledge in this field. Some years ago a systematic study of the structure and properties of tin-rich bearing alloys was commenced by the Tin Research Institute, and a number of new alloys having greater hardness or strength were found. The problem is to investigate their merits as bearings. There are no simple tests which measure all the qualities required in a bearing metal. Meantime, machines have been devised and are in use to measure the fatigue strength of the alloys under various conditions. Some fundamental studies of bearing friction are also being made, and a comprehensive scheme of investigation is under consideration.

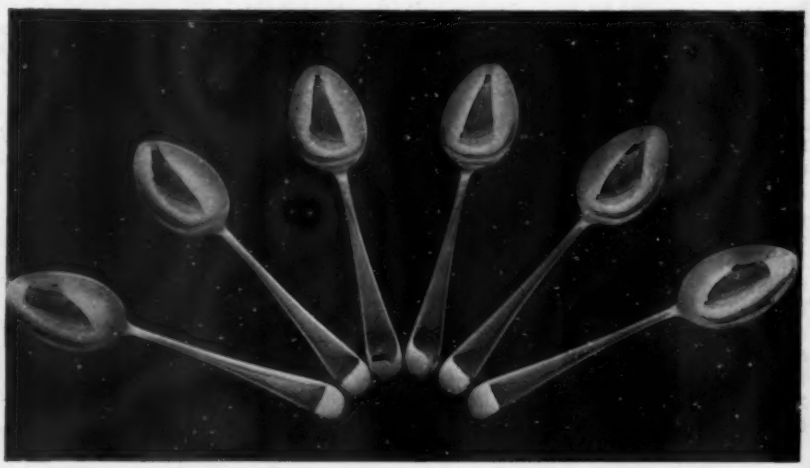
4 The Ministry of Supply permit the Tin Research Institute to impart details to approved applicants.

Speculum Coatings

The reintroduction of Speculum metal is likely to be the most widely noticed development in tin alloys. This name was given to the metal mirrors of ancient times. These were usually made from polished bronze castings, various proportions of tin and copper being used. In the 18th and 19th centuries the alloy again became prominent. Its use enabled striking progress to be made in astronomy, where for a time the design of metal reflector telescopes outstripped the slow development of the refractor type using glass lenses.

Speculum is, however, an extremely difficult metal to cast and fabricate. The new development is the devising of a practical process by which it can be electro-plated. In this form it can be applied as a decorative finish to baser metals. Speculum has a colour and appearance closely resembling that of silver, but its high reflective qualities are combined with an exceptional resistance to tarnish, particularly within doors.

Fig. 7.—Spoons electro-plated with Speculum metal.



It has already been adopted as a finish for tableware (Fig. 7), and is being tried out for a great many other purposes, a feature being that it lacks the cold bluish tint associated with chromium, and its use for internal decorative metal-ware can be associated with a wider variety of colour schemes.

In sum it may be said that the past three years have seen a search for substitutes and a practical trial of economy measures of unparalleled intensity. The net result is that economy has chiefly been achieved by eliminating uses not essential to the war effort. The high hopes of substitution have subsided, and the previously established usages have, broadly speaking, been justified as best when normal conditions of choice obtain. But it can also be said that modern scientific methods of investigation have been directed to the uses of tin for only a few years, and that the progress already made justifies confidence that many new and valuable developments in the art of using this metal will be forthcoming.

Some Thoughts on Medium and High Tensile Wrought Alloy Steels, Present and Future

By J. H. G. Monypenny

Directions issued by the Ministry of Supply regarding the use of individual steels listed in B.S.S. 970 are dictated by the extent of the available supplies of alloys and the necessity for conserving them. The need for economy of these alloys still exists, and is likely to continue for some time in the post-war years. Consideration is given to the types of low alloy steels developed in the last few years and to the need for eliminating restrictions from specifications for alloy steels in the post-war years.

THE selection of wrought alloy steels to meet medium and high tensile requirements for general engineering purposes has been largely governed during the last three or four years by the collection of En specifications comprised in B.S.S. 970 and by the directions issued from time to time by the Ministry of Supply, regarding the way the individual steels in this collection may be used, depending on the tensile strength required and the size—or "ruling section" as they term it—of the article in which it is to be obtained. These directions have been dictated by the extent of the available supplies of essential alloys and the necessity for conserving them as much as possible—a necessity, it may be noted, which is hardly less urgent now than in the earlier war years, and which will very probably persist in the post-war period for the sake of economy, if for no other reason. One of the most important features of B.S.S. 970 was that it correlated the properties obtainable by heat-treatment from various steels with the ruling sizes of the bars or forgings at the time they were heat-treated, a feature entirely ignored in many earlier specifications. This emphasis on mass effects was the basis of the drive for economy in alloys as it showed the extent to which various steels of low alloy content could replace those more highly alloyed in obtaining desired properties. In other words, it defined the properties obtainable from each steel far more specifically than had generally been the case, not only in specifications, but in the minds of many engineers and other steel users. It also presented a new idea to many of them—namely, that the composition of the steel to be used when a given range of tensile strength was required would often vary with the size of the article in which these properties were to be obtained. One might take as example the well-known B.S.I. specification S 11. Steel made in accordance with this specification was probably more widely used than any other in aircraft construction before the war. The tensile and impact properties required are quite moderate—a tensile strength of 55–65 tons per sq. in. coupled with a minimum impact value of 40 ft.-lb.—and they can readily be obtained from steel of the specified composition in sizes up to at least 6 in. diameter. The specified steel, however, is quite highly alloyed—2·75–3·75% nickel, 0·5–1·0% chromium, to which, if desired, up to 0·65% molybdenum could be added—and its use for the small sizes—e.g., up to 1½ in. or 2 in.—which constituted a great part of the material required for aircraft construction, was just a sheer waste of valuable alloy, because the required properties could be obtained in sizes up to about an inch from a 1% chromium steel, and up to about 4 in. diameter from chromium-molybdenum or manganese-molybdenum steels with a total alloy content, including manganese, of less than 2½%.

It should not be inferred from this that the wasteful use of these relatively highly alloyed steels was universal before the war; it was undoubtedly widespread, but many of the larger producers of motor-cars and other road vehicles, for example, were well aware of the economies obtainable by using suitable low alloy steels offered to them by the more enterprising steel-makers, and had made extensive use of this knowledge.

Much of the saving in virgin alloys during the last two or three years, however, has resulted from a more effective use of alloy steel scrap—particularly turnings, in which form, it has been estimated, some 30% of all steel in ingot form eventually becomes available for re-use by the steel-maker—and it is to this fact that certain additions to the original En series—namely En 100 and En 110—may be related. When the controls were first applied, the drive for economy in alloys was based largely on an extended use of the manganese-

molybdenum type of steel, but this led to considerably increased requirements of these two alloys in virgin form, because relatively little scrap of this type was available—and in any case manganese is largely lost on remelting—whereas much scrap containing valuable amounts of nickel and chromium together, sometimes, with molybdenum and resulting from the working up of steels containing these alloys, which had been previously supplied to the engineering industry, was available and tended to become almost a drug on the market because it could only be used for purposes for which the higher nickel-chromium-molybdenum steels were permitted. Considerations of this nature led eventually to the appearance of specifications En 100 and En 110, which provide an alternative outlet for the effective use of this scrap in producing economically steels, containing nickel, chromium and molybdenum at relatively low levels, suitable for medium and high ranges of tensile strength in sizes for which previously only the manganese-molybdenum and chromium-molybdenum (En 19) steels had been permitted.

When higher tensile strength—coupled, of course, with reasonable toughness—is required in parts of large diameter, the nickel-chromium-molybdenum steels to specifications En 24, En 25 and En 26 continue to fill the bill. The ranges of composition set out in these specifications are probably generally regarded as being at least as satisfactory, from the point of view of obtaining the required properties, as any others, but one wonders whether it is really necessary for the limits for each alloy to be so narrow. The test results set out in the following Table and quoted from a paper by Mr. H. Bull* (to which further reference will be made later) show that so long as the total content of nickel, chromium and molybdenum is round about 3½%, the individual contents may vary appreciably without the tensile and Izod values falling outside permissible limits, even when no particular care is taken to adjust tempering temperatures.

NICKEL-CHROMIUM-MOLYBDENUM STEELS.
Oil Hardened, 830° C., and Tempered, 620°–630° C.

Composition.					Tensile Strengths (T) and Impact Values (I) from Bars.							
					1½ in. Diam.		2½ in. Diam.		4 in. Diam.		6 in. Diam.	
C.	Mn.	Ni.	Cr.	Mo.	T.	I.	T.	I.	T.	I.	T.	I.
0·34	0·50	2·11	1·41	0·33	66	74	66	69	65	66	65	51
0·46	0·71	1·10	0·97	0·26	69	56	71	48	69	60	67	40
0·41	0·72	1·86	1·30	0·34	72	64	73	48	72	48	67	51
0·35	0·53	2·90	0·90	0·46	72	62	75	50	70	62	65	54
0·40	0·71	2·86	0·92	0·47	72	60	75	53	71	44	72	41
0·43	0·76	2·20	0·66	0·50	72	55	76	41	72	49	70	46
0·37	0·57	2·15	0·62	0·50	74	59	74	55	66	33	68	25
0·38	0·55	2·84	0·86	0·49	74	56	76	55	66	62	71	39

Case-hardening steels remain much as they were when control was first applied, the only addition to the original En steels of this type being that containing 1·25–1·75% manganese, and intended for core strengths of not less than 40 tons per sq. in. It is thus intermediate in strength between the ordinary carbon case-hardening steel (En 32) and the nickel or nickel-molybdenum types. The two specifications for this high manganese steel cover normal and free-cutting varieties.

Nickel thus remains the key alloy for obtaining high core strengths in case-hardening steels, though its content has been reduced in many cases as a result of partial replacement by molybdenum or chromium or both. Whilst this is partly due to the directions of the Ministry of Supply, it is well to note that it had been in evidence for some years prior to the war, thus the 5% nickel type had often been replaced by the nickel-chromium variety (En 36) without loss of properties and with probably a slight gain in case-hardness.

Suggestions, such as those given above regarding nickel-chromium-molybdenum steels, that composition ranges in specifications might be widened may be regarded as heresy by those who preach the advantages to the user of handling material falling within narrow composition limits. These advantages presumably arise mainly in heat-treatment operations and stress has been laid on the inconvenience to the user, who buys his steel in bloom or billet form and has finally to heat-treat it after working it to required shapes, of having to adjust his heat-treatment temperatures for different batches of steel in order to obtain the same physical properties from each. Most people will agree with the desire to avoid such inconvenience. If, however, the materials supplied, despite differences in composition, respond in similar fashion to the same heat-treatment, it would seem that practical requirements are met, and closer restrictions in composition ranges merely cause more trouble to the steel-maker without any appreciable advantage accruing. These considerations, of course, apply to other steels, as well as the nickel-chromium-molybdenum type, and they are almost certain to arise in the post-war period.

One may perhaps ponder on what is likely to happen in the post-war years, when "controls" and "directions" are things of the past. Will B.S.S. 970 still be basis of alloy steel metallurgy or will industry revert again to something like the plethora of specifications—there were hundreds of them, many firms having their own individual varieties—which governed the supply of steel in pre-war days? It may be that B.S.S. 970 will persist, though perhaps modified to a greater or less extent; modifications based on experience and which produce useful results should always be welcomed, but one hopes that the steel industry will not again have to cope with numerous specifications whose requirements would seem to have been based on the personal fads of the particular specification makers who evolved them, rather than on actual needs. One could hardly obtain a better illustration of this sort of thing than is afforded by a comparison of the composition limits called for in B.S.I. specifications S 11, S 65 and S 81, and set out below :—

Spec.	C.	Mn.	Ni.	Cr.	Mo.	Tensile Strength.
S 11	0·25–0·35	0·45–0·7	2·75–3·75	0·5–1·0	0·65 max.*	55–65
S 65	0·22–0·28	0·35–0·65	2·75–3·5	1·0–1·4	0·65 max.*	65–70
S 81	0·28–0·35	0·7 max.	3·0 –3·75	0·5–1·3	0·5 max.*	65–75

* Optional.

The differences between these specifications in the composition limits which they set for individual elements would seem to defy any logical or even reasonable explanation.

The question as to whether or to what extent specifications for steel should contain clauses calling for the composition of the steel to be within more or less narrow limits has been debated on more than one occasion, and arguments have been advanced both for and against the inclusion of such clauses. Much will depend on the

* "The Economic Utilisation of Alloy Steel Scrap." *Iron and Steel*, June, 1943.

purpose for which the steel is to be used, and arguments which might have considerable weight in the case of heavy forgings—e.g., for large turbo-generators—would probably be of little importance in the case of bars or forgings whose ruling size does not exceed 6 in. or so. As the latter steels, however, constitute a very large part of the alloy steel used at the present time, and are likely to do so in the post-war years, and as, moreover, they are the type of alloy steels governed at present by B.S.S. 970, it may be useful to narrow the discussion to these. Generally speaking, the purchaser is primarily interested in obtaining stated properties, and if, as is very often the case, he obtains his steels in the heat-treated condition from the steel-makers, subjecting them in his own works only to machining operations, his requirements are essentially physical properties, and so long as these requirements are satisfied, the steel-maker should be allowed complete freedom as regards the chemical composition he uses to obtain them. There is nothing new in this idea, of course ; it is embodied in the old and well-known B.S.I. specification S 2, and it was also evident before the war when various steel-makers offered particular brands of their steels as possessing guaranteed physical properties, but gave no limits of composition. Probably some steel users will dispute this idea and say they must have this or that type of steel. One agrees, of course, that in what they would probably call a normal market, free from controls and restrictions and with plentiful supplies of raw materials, the purchaser may claim the right to have the steel he desires—provided, of course, he is willing to pay for it ! It seems probable, however, that many of these preferences for certain types of alloy steels for certain purposes—when they did not arise merely because " such and such steels had always been used for these jobs "—sprang from the idea that each alloy had specific effects when added to steel, thus some made the steel tougher, other made it harder, and so on. Such ideas are probably relics of the days when heat-treatment was less understood and much less practised than now, when steels were used more often than not in the forged or rolled condition, and if heat-treatment was allowed—it was on more than one occasion characterised as a means of bolstering up poor steel, the inference being that good steel did not need it—it was limited to normalising. There are, of course, differences between the effects produced by different alloys, but they are very largely concerned with the reduction of mass effects during hardening, and some alloys are far more efficient in this respect than others ; on the other hand, differences in toughness between different low alloy steels heat-treated to give the same tensile properties are often due to differences in steel-making conditions rather than to the actual alloy added to the steel.

There are occasions when something more than mere physical properties is required even in heat-treated bars or forgings supplied to a customer for machining to their final shape. One important example of this arises when the machining of bars is largely eccentric to their axes ; unless the bars are free from internal stress they are likely to warp when machined in this way. Similar effects of internal stress may also arise in forgings. Freedom from internal stress in either heat-treated bars or forgings, however, is bound up with the methods of heat-treatment used, and although these are influenced by the actual alloy content, specifying some particular composition, even between very close limits, would not by any means necessarily ensure the absence of stress in the treated bars ! Undoubtedly the best procedure for the user in such a case is to let the steel-maker know that he requires the material as stress-free as possible. The steel-maker—if he is wise—will choose a steel which is free from temper brittleness and of such composition that it will give the desired physical properties when tempered at as high a temperature as possible, and preferably not less than 600° C., because the higher the tempering temperature, other things being equal, the more readily and completely are hardening stresses removed ; he will also see that the tempering operations —more than one may be advisable—are carried out in such a way they do not themselves introduce stress, and that subsequent cold straightening is not required.

There may be official objections to the use at the present time of specifications on the lines of S 2, on the grounds that the absence of composition limits might perchance lead some steel-makers to use a greater amount of alloy for a given steel than was really necessary, but these objections will vanish with control, and it is to be hoped that the use of specifications on the lines of S 2 will extend.

When steel is supplied in billet or bloom form to be hot-worked and finally heat-treated by the user, something more than merely the capacity for giving desired properties is justifiably required from the steel. These properties should be obtainable by some reasonably standardised heat-treatment, otherwise, if the required hardening or tempering temperatures vary from batch to batch the user will be under the necessity of keeping every batch of steel entirely separate during its processing through his works, and of adjusting his heat-treatment temperatures to suit each batch. As mentioned earlier, one can appreciate the inconvenience which could thus arise, but it is questionable whether it is necessary to restrict composition within narrow limits in order to achieve the required uniformity. A clause in the specification calling for the specified properties to be obtainable by hardening and tempering at stated temperatures, or preferably within certain narrow temperature ranges—e.g., a stated temperature ± 10° C. —would seem to be at least as effective in achieving the desired uniformity ; the clause should, of course, state what hardening medium—i.e., water, oil or air—is to be used, and also how the test-piece is to be cooled after tempering—i.e., whether air cooling is essential or whether some faster rate, such as oil or water-quenching, is allowable.

Possibly the advocates of narrow ranges of composition for each steel will suggest that the author is really asking the user to condone careless steel-making, that steel can be made within narrow composition limits and that there is no reason why the steel-maker should require all this license. Apart from the obvious retort that the steel-maker has generally a far greater knowledge than his customer of the suitability of the various grades of steels which he makes for giving specified physical properties—it was not unknown before the war for the physical properties demanded by a specification to be practically unobtainable from steel made within the specified composition limits—the author would put the question in the reverse way ; if the steel-maker supplies steel giving the specified properties when heat-treated under the stated conditions, why should he be subjected to further unnecessary restrictions, unnecessary because they do not make the steel one whit more suitable

for the required purpose ? This question would seem to be of considerable importance in the post-war years, when it will still be necessary to make the best use of alloy steel scrap so that our imports of virgin alloy are not higher than they need be. Alloy steel scrap is a variable raw material, and incidentally not easy to sample—in fact, the only certain way in many cases may be to melt it down as a furnace charge and then sample the molten bath. It might or might not then be possible to finish off such a charge so that the composition of the material tapped lay within some narrow specified limits, but the probability that it could be brought to a composition which would give the required physical properties when treated in the specified manner would certainly be greater.

When considering the economical utilisation of alloy steel scrap, reference may again be made to Mr. Bull's very interesting paper on this subject. He showed that from the point of view of recovery of alloys—more particularly, of course, those readily oxidisable, such as chromium and manganese—the basic electric arc furnace was most efficient, but that the basic open-hearth, when properly used, was a close second, whereas the acid open-hearth was a rather poor third. The basic open-hearth furnace is coupled in many engineers' minds with the idea of lower quality steel, probably because it has been largely used as a mass producer of cheap steels often made from raw materials quite unsuitable for use in acid open-hearth furnaces. There is no need, however, to work the furnace in this way, and the idea that poor quality is a necessary feature of steel melted on a basic hearth should surely have been dispelled by now by the fact that the product of the basic electric arc furnace is regarded in many quarters as the highest quality steel produced, and, in point of fact, commands a higher price than the product of the acid open-hearth furnace. Electric heating may allow certain slag-metal reactions to be carried out more effectively or more readily than a furnace fired with producer gas, but experience has shown that if the basic open-hearth furnace is fed with raw material which would be suitable for the acid open-hearth furnace and worked in a proper manner, the quality of the product compares very favourably with that of the acid open-hearth, and moreover the recovery of chromium from the scrap is high. A basic open-hearth furnace may thus have definite economic advantages, and it would be a pity if its use was prevented or minimised by prejudices based on misconceptions.

No one yet knows what post-war conditions will bring, but it seems certain that if we are to increase the volume of our exports to the extent which economists say will be necessary to maintain a good standard of living, production costs will have to be kept down. Unnecessary restrictions and requirements in steel specifications increase costs of production and lead eventually to increased prices ; why increase the latter unnecessarily by insisting on restrictions or requirements which serve no useful purpose ?

MACHINING LIGHT ALLOYS

ALTHOUGH at the outbreak of war live light alloy industries were functioning in this country and were meeting the demands of normal peace-time activities the change from peace to war made much greater demands on producers and forced users to give closer attention to the various operations involved in processing to obtain finished products possessing the necessary characteristics necessitated by service conditions. Among the operations involved that of machining has been given special attention and recently two sets of recommendations on the subject have been published, one dealing with light alloy castings and the other with wrought aluminium alloys.

Machining Light Alloy Castings

Primarily, the recommendations in this booklet are intended for those who have little or no acquaintance with light alloys, but the extensive use of light alloy castings has brought the publishers into close contact with a multiplicity of problems which also have a special interest for the expert machinist and production engineer. Light alloy castings can be machined at much higher speeds than steel or brass, and the tools used must be properly shaped to prevent chips adhering to cutting edges, and to avoid other troubles peculiar to light alloys, therefore time spent in studying these points will be amply repaid.

The cutting angles, speeds, feeds and cuts recommended are representative of good machining practice ; however, it is recognised that each casting and operation must be considered on its merits, and adjustments to angles and speeds may have to be made to suit individual circumstances. This booklet presents in simplified form the average practice evolved for the machining of light alloy castings. It is published by Birmingham Aluminium Castings (1903) Co., Ltd., Dartmouth Road, Smethwick, 40, Birmingham. Price 1s.

Machining Wrought Aluminium Alloys

Wrought aluminium alloys may be readily machined, but the technique required differs in some respects from that for other common engineering metals, and this booklet has been compiled to put before the user of these alloys the most recent information upon the subject. Especially is it intended for production engineers, machine-shop superintendents and machinists.

The booklet is produced as a Wrought Light Alloys Development Association Information Bulletin, and those familiar with the bulletins previously published by this Association will understand when we say that the high standard both of the text and production of this recent Bulletin maintains that of previous booklets.

The machinability of aluminium and its alloys is discussed, and speeds and feeds are tabulated for groups of alloys. Reference is made to the characteristics of the various cutting materials used, but major attention is given to tool shapes for particular machining operations on aluminium alloy parts.

Published by the Wrought Light Alloys Develop, ment Association, Union Chambers, 63, Temple Row-Birmingham, 2, at the nominal price of 1s.

Special attention will be directed to progress in Aluminium and Aluminium Alloys in a later issue.

Copper and Copper Alloys

A Survey of Technical Progress during 1944

By H. J. Miller, M.Sc.

(*Copper Development Association*).

Although war-time conditions continue to impose restrictions on the publication of some development data in the copper and copper alloys fields, a remarkable number of papers and reports have been published during the year. The quality of the work done and the high rate at which it is maintained indicate that the industry is not only concerned with increased production, but is persistent in its efforts to improve the quality of products. No fundamentally new methods have been developed, the trend has been towards the improvement of established practice to meet the particular demands of war-time production. This general survey incorporates the more outstanding contributions to progress during the present year.

DURING 1944 the publication of technical papers devoted to copper-base materials has been maintained at a high rate and quality, which is remarkable considering the war-time conditions. In regard to patents, the situation is very different, since censorship regulations have resulted in a total withholding of publication of the more important of these. Thus it is not possible to make a complete review of all technological progress which has been made in 1944, and this review is of necessity confined to a consideration of published papers, of which by far the major proportion have originated in U.S.A.

Production Practice

As pointed out in a review of U.S. conditions made by Crampton,[1] the general features of war-time production practice for copper-base materials have not differed greatly from those previously established ; the ultimate products have been different and there has been a redistribution of requirements as between copper and its alloys, and between the various alloy groups, but there have been no fundamentally new methods. Many specialities amongst alloys have been taken off the available list because of the need for rationalisation to give the increased outputs required and thus greater reliance has been made on the standard alloys, though Crampton expected that there would be a return to the manufacture of special alloys.

In manufacturing practice for strip, sheet, rod, etc., principally in brass, Crampton has outlined the outstanding trends, prominent amongst which are the use of larger low-frequency induction melting furnaces, the more extended use of water-cooled moulds, the casting of strip ingots up to 1,000 lb. weight for cold rolling, or 2,000 lb. or more for hot rolling, and generally much heavier fabrication equipment to cope with the large sizes involved. Thus it is mainly in the modernisation of production practice that there has been much change, and it cannot be said that any novel methods have been applied, except under special isolated conditions.

The continuous casting of metals was discussed at a symposium of American Institute of Mining and Metallurgical Engineers, in February, 1944, but the contributed papers have not been published and only an extended report by Lippert[2] is available. The continuous-casting of copper alloys is understood to have been applied in U.S.A. for part of war-time programmes, though the tonnage of metal so cast is only a small—but by no means insignificant—proportion of the total ; on the other hand, the development of continuous-casting methods for other metals of lower melting points has made very considerable commercial headway. This points to the fact that it is only a question of time—with its attendant improvement of equipment and materials—before continuous-casting comes to be the standard method, with the now accepted practice used for special alloys only, though as far as this country is concerned it will mean that there will have to be a " rationalisation " of material requirements so as to provide the large tonnages necessary by this process, owing to the lack of versatility.

In European practice, it would seem that the Erichson process of casting flat slabs in a horizontal mould has been further applied,[3] but little is yet known of practice on the continent.

From the practical aspect of tube drawing, manufacturers may find the paper by Baldwin and Howald[4] of assistance in calculating dimensional changes when hollow-sinking.

Powder Metallurgy Practice

As usual, considerable interest has been displayed in powder metallurgy, and it is now more widely appreciated that at present it is only for special purposes that this method is capable of economical application. The method can provide certain structures or metal combinations that are not obtainable by other means, and it is in these instances and especially where close dimensions also are involved, that the high costs of materials and fabrication can be considered ; even then there must be substantial numbers of any given design. Consequently, this method of fabrication has not made spectacular progress, but very steadily there has been a continual expansion in the spheres of application.

Victor and Sorg[5] have written about design factors, and Rossman[6] has reviewed all the available patents concerning electrolytic methods of manufacturing copper

1 D. K. Crampton. " War's effect on wrought copper alloys and their production." *Mining and Metallurgy*, 1944, **25**, 297.

2 T. W. Lippert. " Continuous casting of metals." *Iron Age*, 1944, **153**, Feb. 24, p. 48.

3 F. Erichson. " The casting of metal roller slabs." *Metal Industry*, 1944, **64**, 232.

4 W. M. Baldwin and T. S. Howald. " Dimensional changes encountered in tube sinking." Amer. Soc. Metals, 1944, **33**, 88.

5 M. T. Victor and S. A. Sorg. " Design of powder metallurgy parts." *Metals and Alloys*, 1944, **19**, 584.

6 J. Rossman. " Review of patents on electrolytic methods for making powdered metals." Electro-Chemical Society, Preprint, April, 1944.

Fig. 1.—A group of copper-base components made from powdered metals.

powder. Papers by Osborn and Tuwiner[7] and Cordiano[8] have described both the production processes and applications of copper powder in U.S.A., while an article by Greenwood[9] has dealt with the recent British production of copper powder. A number of other papers contributed to the symposia of either the American Electrochemical Society or the American Society of Testing Materials have also been related to copper powder practice, notably those by Crane and Bureau,[10] Kalischer,[11] Delisle,[12] and Kuzmick.[13] The latter considered metallic friction materials for brake and clutch linings in replacement of asbestos and similar non-metallics for severe service applications; he indicated that satisfactory composite materials have been compounded on the approximate basis of copper powder 60 to 75%, tin and zinc powder 5 to 10%, lead powder 5 to 15%, graphite powder in small amounts and an abrasive powder, such as silica or emery, in amounts of 2 to 7%. This particular use is understood to account for a very considerable proportion of the present output of copper powder and the further potentialities are considerable.

Cast Copper-base Alloys

A considerable amount of attention has been devoted within recent times to the copper-base materials for casting, and during 1944 the results of several fundamental researches have been published; in addition, several papers of a practical nature have appeared, the origin of several of which is related to the conservation of raw materials, the demand for pressure-tested or otherwise first-class cast products, or some other wartime requirement. From amongst these various papers there emerges a wealth of information which cannot help but make a permanent useful contribution to this trade.

Among the outstanding papers are two by Baker, Child and Glaisher,[14, 15] who have been concerned with the gas reactions occurring with the commercial copper-tin alloys, including phosphor bronzes and gunmetals. It was established that the causes giving rise to severe unsoundness were the absorption of hydrogen by the molten metal and the subsequent reaction of the excess hydrogen, evolved in the early stages of solidification, with oxygen also present either in the molten metal or picked up during pouring. The actual solubility of hydrogen in the copper-tin alloys has been determined by Bever and Floe,[16] who find that this is progressively lower as the copper content is reduced, there being no significant solubility of hydrogen in tin.

With melts which were accorded a standard gassing treatment, by maintaining hydrogen atmosphere over the molten metal, Baker and his colleagues applied various oxidising fluxes and observed the influence of these on the results obtained on casting. They confirmed the beneficial effects of certain oxidising fluxes, but found that these could not be applied to all commercial materials, such as the normal foundry melts containing appreciable amounts of zinc or phosphorus, because it was necessary to remove practically the whole of the zinc and phosphorus before the hydrogen was sufficiently eliminated. This showed the limitations of flux treatment methods, and in consequence they advocated the removal of hydrogen by gas scavenging processes, the preferred method being to bubble nitrogen through the molten metal. This completely degassed the melts and made it possible to obtain cast test bars of high density and excellent mechanical properties.

Production of Pressure-tight Castings

In foundry practice, the condition of the molten metal is only half the story, and the final result is judged on the results obtained on castings, which latter are possibly of complex shape. In their second paper, Baker, Child and Glaisher investigated the relationship between mechanical properties, density and pressure tightness of simple castings made in green sand moulds. The casting chosen for the investigation was a disc having a heavy section in the centre and a thin flange, and this was cast with a small feeder section so that it was imperfectly fed. It was found that there was an optimum gas content to be aimed at in the molten metal, and that if the metal was completely degassed then there was excessive shrinkage which became concentrated at certain positions and thus there was failure in the pressure test; under ideal conditions of feeding, of course, this effect would not have been experienced.

With metal of an intermediate gas content—such that the resultant density was of the order of 8·6 to 8·75—a disseminated type of porosity was obtained, and this did not interfere with pressure tightness. With metal of an excessively high gas content, the resultant porosity was again of an undesirable type. As regards the different

7 W. H. Osborn and S. B. Tuwiner. "Electrodeposition of copper powders." Electro-Chem. Soc., 1944, **84**.

8 J. J. Cordiano. "Copper in powder metallurgy." Electro-Chem. Soc., 1944, **84**.

9 H. W. Greenwood. "British electrolytic copper powder." METALLURGIA, 1944, **30**, 181.

10 E. V. Crane and A. G. Bureau. "Presses and processes for metal powder products." Electro-Chem. Society, 1944, **84**.

11 P. R. Kalischer. "The Determination of particle size in powder metallurgy." Electro-Chem. Society, 1944, **84**.

12 L. Delisle. "Bonding metal particles by heat alone without pressure." Electro-Chem. Soc., 1944, **84**.

13 J. F. Kuzmick. "Metal powder friction materials." Amer. Soc. Test. Materials. "Symposium on Powder Metallurgy," 1943.

14 W. A. Baker and F. C. Child. "The Removal of gases from molten bronzes." *J. Inst. Metals*, 1944, **11**, 349.

15 W. A. Baker, F. C. Child and W. H. Glaisher. "The effect of shrinkage and gas porosity on the pressure tightness and mechanical properties of bronze sand castings." *J. Inst. Metals*, 1944, **11**, 373.

16 M. B. Bever and C. F. Floe. "Solubility of hydrogen in molten copper-tin alloys." *Amer. Inst. Min. Met. Eng., Tech. Pub.*, **16**, 88.

alloys employed in the experiments, it was found that the leaded gunmetals were superior in that the lead particles tended to fill the small shrinkage cavities which would otherwise have resulted in porosity; the phosphor bronzes of high phosphorus content were found to react with the moist moulding sand, so that there was absorption of some hydrogen and oxygen by the molten metal, even though the latter was originally prepared gas-free, but the resultant porosity was not very excessive, and in fact this group of alloys was rather favoured by the investigators for the production of pressure castings.

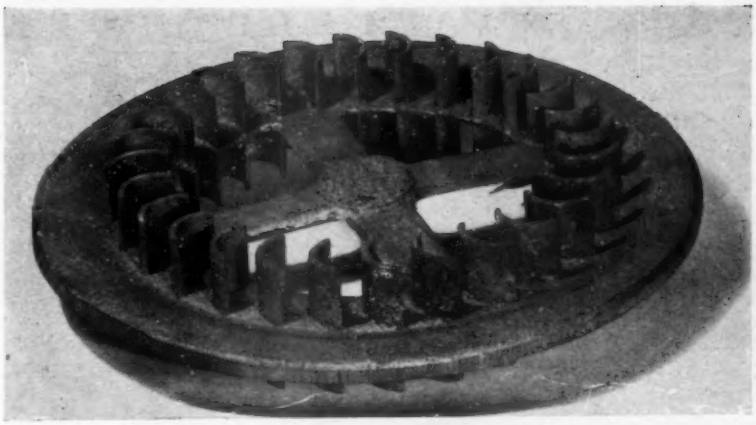


Fig. 2.—Alternator rotor casting, approximately 14 in. diameter, made in brass (B.S. 1028), the use of which has been widely repractised in place of gunmetal during the war period.

Further Observations on Soundness and Testing of Castings

Support for the use of oxidising flux treatments in the production of chill-cast phosphor bronze was forthcoming from the work of Pell-Walpole and Kondic,[17, 18] who, in addition, determined the optimum conditions—i.e., temperature and rate of pouring—necessary to achieve maximum strength and soundness.

Some interesting observations on the unsoundness of gunmetal which can result from the excessive absorption of carbon-monoxide from furnace atmospheres were contained in an article by Covington,[19] who described a foundry operating with high-frequency electric induction melting furnaces; the troubles were traced to excessive absorption of carbon from the furnace lining, a matter which was aggravated by the high temperatures which were reached and which was rectified by control of the latter. This indicates that there must be a solubility of carbon in copper or copper-base alloys at high temperatures, a matter which is not generally recognised.

Hudson[20] has made a careful study of the suitability of various alloys of the gunmetal type for the production of castings subject to high-pressure tests, and he finds that there is a great benefit attaching to the presence of 5% of lead; the alloy composition he recommended for high pressure purposes, i.e., 2,000 lb./sq. in. test pressures, was 83% copper, 7% tin, 5% lead, and 5% zinc, and this gave superior results to the conventional gunmetal of 12% tin content. Nickel additions were also found to be favourable. A further paper in the investigation of cast red brass by the Bureau of Standards[21] has been published, and the properties of manganese bronze containing lead additions have been reported on by Halliwell.[22]

The methods of testing involved in the production of castings have been considered by Smith,[23] George[24] and Baker,[25] the former of whom suggested that A.S.T.M. should reconsider the whole matter of the shape of test-bar castings, with a view to bringing out a test-bar which would be agreeable to all concerned and which would truly reflect the properties of materials.

Centrifugal Casting

Although established for a long period, centrifugal casting is still relatively in its infancy, and the method is considered to be capable of further development and application, as is evident from such papers as those by Hurst,[26] Cox,[27] Zuehlke,[28] Janco[29] and Blackwood and Perkins.[30] These papers were concerned with the basic principles and data applicable to all metals, and indeed there has been no great individual reference to copper-base alloys, apart from the work of Northcott and Dickin.[31] The inter-relation of the various factors involved in centrifugal casting, and particularly the influence of rotational speed, has been studied with considerable success by these authors, who have thrown considerable light on the occurrence of the lamination type of defect.

Dezincification of Manganese Bronze

The dezincification of the beta phase of the manganese bronze group of alloys—whether cast or wrought—is a well-known phenomenon which imposes restrictions on the applications of such materials under corrosive conditions. Hesse, Myskowski and Loring[32] have compared the effects of tin, arsenic, antimony and phosphorus on dezincification in an acid solution, and their conclusion was that tin exerts by far the most beneficial effect, although 0·25% of arsenic also was of benefit. The finding about tin has, of course, been long appreciated—

17 W. T. Pell-Walpole. "Development of a flux degassing process for chill-cast tin bronzes." *J. Inst. Metals*, 1944, **70**, 127.

18 W. T. Pell-Walpole and V. Kondic. "The effect of some variations in casting procedure on the properties of degassed chill cast 10% tin bronze." *J. Inst. Metals*, 1944, **70**, 275.

19 R. T. Covington. "Bronze foundry exercises close control," *The Foundry*, 1944, July, p. 76.

20 F. Hudson. "The use of leaded gunmetal for the production of castings to withstand pressure." *J. Inst. Metals*, 1944, **70**, 407.

21 H. B. Gardner, A. I. Kynitsky and C. M. Saeger. "Physical properties of red brass." U.S. National Bureau of Standards.

22 G. P. Halliwell. "The effect of lead on some mechanical properties of manganese bronze." *Trans. Amer. Found. Assoc.*, 1944, **51**, 837.

23 A. J. Smith. "Evolution of test specimens for non-ferrous castings." Amer. Soc. Test. Mat., 1944. Preprint No. 28.

24 W. B. George. "Some causes of test-bar failures in Navy G and M metals." Amer. Found. Assoc., Preprint, 1944.

25 W. A. Baker. "Test-bars for non-ferrous castings." *Metal Industry*, 1944, **64**, 119.

26 J. E. Hurst. "Speed of rotation in the centrifugal casting process." Inst. Brit. Foundryman, 1944, Preprint No. 799.

27 I. E. Cox. "Centrifugal casting: the design of completely mechanised equipment." Amer. Found. Assoc. Preprint.

28 H. B. Zuehlke. "The hows and whys of centrifugal casting." *Trans. Amer. Found. Assoc.*, 1944, **51**, 773.

29 N. Janco. "Centrifugal casting methods." *Iron Age*, 1944, **153**. Mar. 30, 42.

30 P. Blackwood and J. Perkins. "Centrifugal castings." Amer. Found. Assoc. Preprint, 1944.

31 L. Northcott and V. Dickin. "The influence of centrifugal casting (horizontal axis) upon the structure and properties of metals." *J. Inst. Metals*, 1944, **70**, 301.

32 A. H. Hesse, E. T. Myskowski and B. M. Lorin "Effects of various elements on the mechanical properties and the dezincification of manganese bronze." *Trans. Amer. Found. Assoc.*, 1944, **51**, 821.

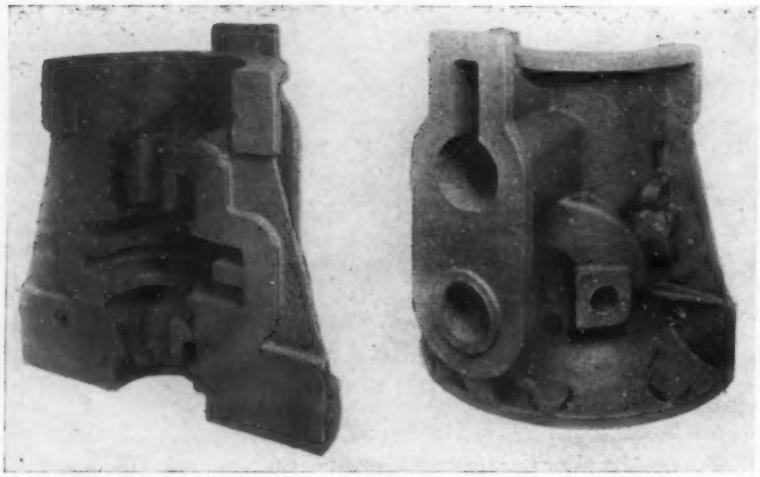


Fig. 3.—Two views of a pump body casing, approximately 450 lb. weight, cast in 86-7-5-2 gunmetal (B.S. 1024), one of the war-time alloys.

as exemplified by the preference for naval brass instead of Muntz metal,—but hitherto it has not been realised that arsenic was of benefit in this connection. From other work on wrought alloys it has also been claimed by Bridgeport Brass Co. that an appreciable arsenic content—namely, of the order of 0·2%—is of benefit in Muntz metal.

Properties of Copper

Observations have been made by Cook and Richards[33] on the annealing effect experienced when rolled copper strip of H.C. quality, and which was originally of various grain sizes and rolled with various reductions, is stored at ordinary atmospheric temperatures. It was found that copper of small initial grain, when rolled with reductions exceeding 95%, acquired a completely self-annealed condition by storing at 18° C. for a period of about one year, while a considerable softening effect was noted after only a few weeks' storage. The ultimate tensile strength of the self-annealed metal was of an unduly low order.

Three papers by Parker and colleagues[34, 35, 36] at the General Electric Company (U.S.) Research Laboratory, have been concerned with the properties of copper at 200° C. This work has embraced a determination of various factors influencing the creep characteristics of commercial copper, though in the course of the work the limiting creep loads have not been determined, and the authors have been content with a comparison of the stress-strain curves resulting from the use of loads of 10,000 lb. to 20,000 lb. per sq. in. In addition, these authors have made high-speed tensile tests on copper at ordinary temperatures.

The constitution of copper containing selenium, tellurium and bismuth has been studied by Eborall,[37] who employed X-ray methods and has suggested some differences from earlier conceptions of the intermetallic compounds formed by copper with selenium and tellurium.

Properties of Copper Alloys

The creep properties of the precipitation-hardening copper-nickel-silicon alloy containing 2·4% nickel and 0·6% silicon have been determined by Jenkins, Bucknall and Jenkinson.[38] The principal finding was that in the fully hardened condition the long-time limiting creep stress at temperatures of 300°–450° C. was lower than that of the alloy in the soft condition. This was in striking contrast with the results of short-time tests. It was suggested that this finding might be generally applicable to precipitation-hardening materials, and if so it shows the danger of reliance on short-time elevated temperature tests.

Several papers have been devoted to the properties of 70–30 brass, and important contributions have been made in respect of stress-corrosion cracking[39] and recrystallisation on annealing.[40, 41]

The long-term American Bureau of Mines' work on the production and use of high-purity electrolytic manganese has led to the installation of a large-scale production plant, as described by Dean.[42] The availability of such high-purity manganese has caused a reinvestigation of the properties of many alloys, and during the past year the ternary copper-zinc-manganese alloy, containing 65% copper, 10% manganese, and 25% zinc, has been the subject of a paper by Long and Graham,[43] who showed that its properties were very different from those of the alloy made from normal commercial purity manganese.

Attention has also been devoted to the copper-manganese-nickel alloys,[44] and it has been shown that with a composition of 22 to 24% each of manganese and nickel, remainder copper, heat-treatment may be applied to give hardness and strength properties which are closely similar to those of beryllium copper. The constitution of the copper-manganese series has been studied by two groups of workers,[45, 46] and certain properties of these alloys have also been investigated in considerable detail.[47]

Further information on the effects of antimony in cast bronzes and gunmetals has been provided

33 M. Cook and T. L. Richards. "The self-annealing of copper." *J. Inst. Metals*, 1944, **70**, 159.

34 D. L. Martin and E. R. Parker. "Effect of cooling rate and minor constituents on the rupture properties of copper at 200° C." *Amer. Inst. Min. Met. Eng., Tech. Pub.*, 1638.

35 E. R. Parker and C. F. Riisness. "The effect of grain size and bar diameter on creep rate of copper at 200° C." *Amer. Inst. Min. Met. Eng., Tech. Pub.*, 1690.

36 E. R. Parker and E. A. Smith. "High-speed tensile impact tests on single crystal and polycrystalline bars of copper." *Amer. Inst. Min. Met. Eng., Tech. Pub.*, 1704.

37 R. Eborall. "Some observations on the mode of occurrence of selenium, tellurium and bismuth in copper." *J. Inst. Metals*, 1944, **70**, 435.

38 C. H. M. Jenkins, E. H. Bucknall and E. A. Jenkinson. "The interrelation of age hardening and creep performance Part II. The behaviour in creep of an alloy containing 3% nickel and silicon in copper." *J. Inst. Metals*, 1944, **70**, 57.

39 H. Rosenthal and A. L. Jamieson. "Stress corrosion cracking of 70–30 brass by Amines." *Amer. Inst. Min. Met. Eng., Tech. Pub.*, 1660.

40 R. S. French. "Grain growth and recrystallisation of 70–30 cartridge brass." *Amer. Inst. Min. Met. Eng. Tech. Pub.*, 1673.

41 H. L. Burghoff and J. S. Porter. "Preferred orientation in annealed 70–30 brass wire." *Amer. Inst. Min .Met. Eng., Tech. Pub.*, 1688.

42 R. S. Dean. "The present status of electrolytic manganese and its alloys." *Amer. Inst. Min. Met. Eng. Tech. Pub.*, 1721.

43 J. R. Long and T. R. Graham. "Physical properties of a 65% Cu, 10% Mn, 25% Zn alloy." *Amer. Inst. Min. Met. Eng., Tech. Pub.*, 1703.

44 R. S. Dean, J. R. Long, T. R. Graham and C. W. Mathews. "Age-hardening copper-manganese-nickel alloys." Amer. Soc. Metals, 1944, Preprint.

45 L. D. Ellsworth and F. C. Blake. "An X-ray study of the copper-manganese binary alloy system." *Jnl. Appl. Physics*, 1944, **15**, 567.

46 R. S. Dean, J. R. Long, T. R. Graham, E. V. Potter and E. T. Hayes. "The copper-manganese equilibrium system." Amer. Soc. Metals, 1944, Preprint.

47 R. S. Dean, E. V. Potter and J. R. Long. "Properties of transitional structures in copper-manganese alloys." Amer. Soc. Metals, 1944, Preprint.

from an investigation by Reichelderfer, Gonser and Blalock.[48]

The Machinability and Welding of Copper-base Materials

Crampton[49] has reported the results of a comparison of the machining characteristics of commercial brasses of varying copper and lead content, as a result of which he concluded that optimum machinability was provided by the alloy containing about 62·5% copper, 3·25% lead, remainder zinc, and which corresponds to the American type of free-cutting brass; machinability was also found to be reduced with increase of cold work. A favourable comment was made on an aluminium-bronze alloy containing 7% aluminium, 1·75% silicon, remainder copper, which was hard and brittle any possessed high machinability, the latter presumabld because of the nature of the second phase. On the other hand, Crampton found that the second phase formed when tellurium was added to brasses did not make for machinability—which is in strong contrast to experience with tellurium additions to copper.

A general review on the welding of copper and its alloys has been contributed by Vreeland.[50]

48 C. A. Reichelderfer, B. W. Gonser, and J. M. Blalock. "Effect of a high antimony content in the tin used in making bronze alloys." *Trans. Amer. Found. Assoc.*, 1944, **52**, 232.

49 D. K. Crampton. "Machinability of copper alloys." *Metal Progress*, 1944, **46**, August, 275.

50 J. J. Vreeland. "Welding of copper and its alloys: recommended technique for oxyacetylene and carbon arc processes." *Amer. Welding Soc. Welding Eng.*, 1943, **28**, Nov., p. 42; Dec., p. 56.

Zinc and Zinc Alloys

By B. D. Darrah, M.A., A.R.S.M.

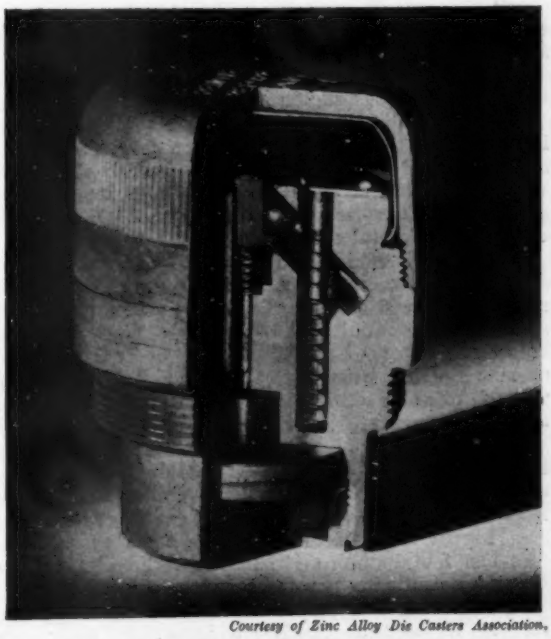
The contribution made to the war effort by the use of zinc and its alloys has, to a considerable extent, been regarded as of a secret character. It is opportune, therefore, to bring to the notice of readers of this metallurgical review, even if only in outline, some of the chief uses of zinc and zinc alloys during the war years. The developments achieved with these materials in meeting the critical requirements of the Services will undoubtedly greatly increase the scope of their contribution to peace-time development in many industries.

ZINC has played a very large part, both in ways old and new, in the war effort of this country. For example, the use of zinc for brass-making, which forms one of the most important "munitions" of war, is so well known that it needs no further reference in this article. Perhaps the most spectacular developments arising out of the present war have taken place in the zinc alloy field, notably in regard to increased uses of pressure die-castings and in the making of dies for drop-hammer and press-die work. These particular developments are dealt with fully later in this article.

So far as the metal itself is concerned, the demands of the new uses have made it inevitable that during the war years many of the old-established uses have had to be temporarily suspended owing to the necessity of conserving supplies for the most essential requirements. Two examples of such suspended uses are the galvanising of corrugated iron sheet and the use of zinc sheet for roofing purposes.

Applications of Zinc

In this country zinc sheet has been rolled almost exclusively during the war for battery can manufacture, the cans being subsequently formed either by the impact extrusion process or by soldering. Sheet zinc has also found minor uses in the radio industry, for instance, in the manufacture of condenser vanes and shielding devices. A considerable tonnage of zinc has been used in plate form for the protection of ship's hulls and boilers. Used in this way, zinc, being anodic to the steel plates forming the ship's hull, is preferentially corroded, thereby protecting the hull itself. Similar considerations may apply in the case of boilers, but it has also been claimed that the protective action of the zinc is due to the removal of dissolved oxygen from the water.



Courtesy of Zinc Alloy Die Casters Association.

Fig. 1.—Showing a die-cast zinc alloy fuse.

An appreciable increase in the use of sheet zinc is anticipated in the building of post-war houses, not only for roofing and tile-clips, but also for weatherings, flashings, damp courses, and so on. Sheet zinc lends itself particularly to prefabrication in relatively large units, and being also easy to work on the site, offers

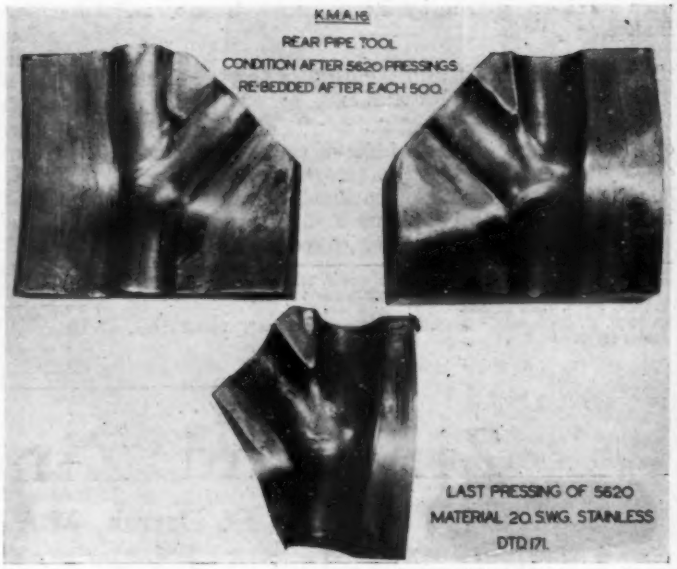
a fast method of building such as is required in the mass erection of houses. Several new systems have recently been developed for rapidly assembling prefabricated roof sections.

Early in the war the rolling of zinc foil was commenced in this country and was finding considerable application, but here again supplies of zinc had to be curtailed and finally stopped. Foil was successfully rolled to 0·008 mm., the thickness normally used for cigarette wrapping, and also 0·004 mm., and even thinner. High purity zinc, slightly alloyed with manganese (U.S. Patent 2011987, British Patent 503488) was needed to produce the thinnest foil, but commercial zinc from a vertical retort plant was also rolled to 0·009 mm. Zinc foil, at thicknesses of 0·02–0·05 mm., was found excellent for wine bottle capsules and such applications, and no difficulty was found in lacquering the product with either colourless or coloured lacquers. The results of cigarette wrapping machine tests on foil of 0·008 mm. thickness were also reported to be excellent. The only difficulty encountered was tarnishing due to condensate water in the high-temperature humidity test, and it is anticipated that foil lacquered on the exterior would be required for wrapping material for export to tropical countries. Zinc foil is immensely stronger than aluminium foil of the same gauge, and the possibility therefore exists of using zinc foil thinner than aluminium for the same application.

The use of zinc wire has been confined almost entirely to spraying through the medium of the wire pistol. For this purpose high-purity zinc (99·99%) is used, and cast into extrusion billets 5 in. diameter and some 30 in. long. These billets are extruded into ¼ in. diameter rod, which is in turn drawn down to wire of the requisite gauge. Zinc spraying is also performed with pistols using molten metal or zinc dust.

The majority of zinc spraying during the war has been for Admiralty requirements. Zinc is the only common metal which will give sacrificial protection to iron and steel, while in addition it exhibits a high degree of corrosion resistance itself. Thus a relatively thin coating of zinc applied by spraying, or metallising, as it is termed, offers an excellent means of rust-proofing iron and steel parts which are too large to be galvanised, such as ships' hulls and superstructures, lock gates, bridgework, etc. Zinc spraying has also been found to enhance the marine anti-fouling properties of superimposed paint. A recent development has been the spraying of non-metallic materials, such as plastics; this has found application in the radio industry for obtaining conducting surfaces where required.

Zinc plating has played an increasingly important role as a war-time protective finish. Its uses have increased as the result of the shortage of other materials. An additional protection is often afforded by Cronak treatment, an acid dichromate dip which forms a thin chromate coating on the zinc surface. This added protection is of particular value in damp conditions of service. Sherardising, the process by which ferrous articles are coated with a zinc rich coating by agitating them in zinc dust at a temperature of 350°–370° C., has also been used to full capacity during the war years.



Courtesy of the Bristol Aeroplane Co., Ltd.

Fig. 2.—Showing a pair of K.M. forming dies.

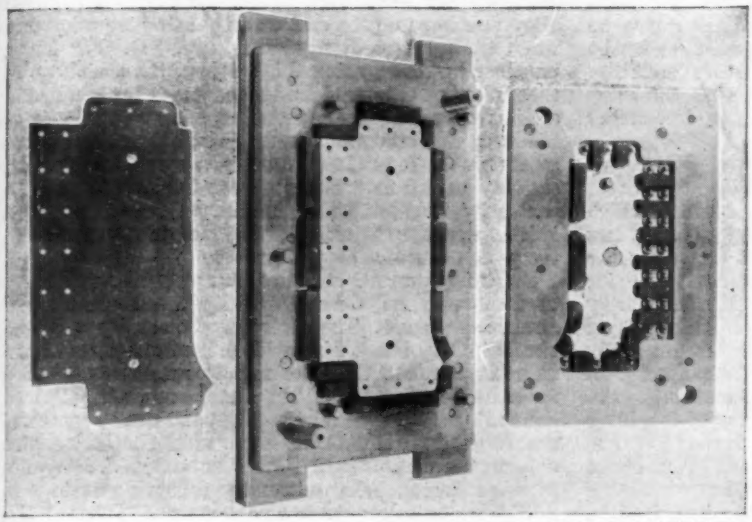
Recent tests on zinc dust paints have also shown that sacrificial protection is given by the zinc to underlying iron or steel, despite the presence of the paint vehicle. Such paints are formulated from an 80/20 zinc dust/zinc oxide mixture, the latter constituent helping to maintain the metallic zinc in suspension and also imparting improved properties to the dried paint film. It is anticipated that the use of such paints will substantially increase. Of the remaining applications of zinc dust, that for smoke for military purposes has of course proved by far the largest.

The greatest developments in the applications of zinc during recent years have been in the alloy field. The two largest applications are: (1) Alloys for die-casting; (2) alloys for press dies and moulds for the forming of sheet metal and the moulding of plastics, etc.

Zinc Die-casting Alloys

Early in the war the die-casting industry was fully mobilised for the mass production of munition stores. In order to assure the necessary high standard of the die castings, particularly with respect to alloy composition and freedom from impurities, the Ministry of Supply decided to standardise on a single alloy with centralised alloy production. In May, 1941, the preparation of a British Standard Specification covering high-purity zinc and zinc alloys for die-casting was authorised, and this was published early in 1942 (B.S. 1003/1004). This specification covers the basic 99·99% zinc which is necessary for these alloys, and also two alloys for die-casting, termed Alloy A and Alloy B, whose composition is as follows in virgin ingot:—

	Alloy A, %		Alloy B, %
Aluminium	3·9–4·3	..	3·9–4·3
Copper	0·03 max.	..	0·75–1·25
Magnesium	0·03–0·06	..	0·03–0·06
Iron	0·075 max.	..	0·075 max.
Lead	0·003 „	..	0·003 „
Cadmium	0·003 „	..	0·003 „
Tin	0·001 „	..	0·001 „
Zinc	Rem.		Rem.



Courtesy of Sheet Metal Industries.

Fig. 3.—Showing a blanking and piercing die.

Zinc alloy die-castings have figured in a wide variety of armament parts. Probably the most well-known applications have been the trench mortar bomb fuses. The 2 in. fuse is shown in Fig. 1. Many millions of these fuses have been die-cast, usually in multi-impression dies, casting four at a time. The advantages of production by the pressure die-casting process are well illustrated by this application, in which the following parts of the fuse are die-cast in zinc alloy: Body, top and bottom end caps, shutter, striker, disc and ball. The two external threads on the body have usually been die-cast complete, as have also the threads on the two end caps. It will therefore be seen that only the simplest machining operations are required to complete this component ready for assembly.

Other well-known armament parts which have been pressure die-cast in zinc alloy include 25-pounder ammunition fuse components, anti-tank mine fuses, mortar bomb tails, tank periscopes, Bofors gun foresights, No. 68 anti-tank rifle grenades, tank carburettors, hand grenade fuses and shell nose caps and percussion fuses. Many other components of a less spectacular nature have been die-cast in zinc alloy, such as radio chassis and instrument housings.

Before zinc alloy die castings were accepted by the authorities concerned for many of these applications, exhaustive tests were carried out under service conditions. In particular, firing tests on zinc alloy fuses were performed at temperatures as low as — 68° C. without a single case of failure. A memorandum entitled "Zinc Alloy Pressure Die-castings for Service Applications" was published by the Ministry of Supply in November, 1943, which drew particular attention to the use of these alloys at low temperatures.

The composition of the castings is also specified, and it is interesting to note that the die-caster has been allowed a small tolerance on the impurities iron, lead, cadmium, tin, and copper in the case of Alloy A. The limits for the composition of the castings are as follows :—

	Alloy A. %		Alloy B. %
Aluminium	3·9–4·3	..	3·9–4·3
Copper	0·10 max.	..	0·75–1·25
Magnesium	0·03–0·06	..	0·03–0·06
Iron	0·10 max.	..	0·10 max.
Lead	0·005 „	..	0·005 „
Cadmium	0·005 „	..	0·005 „
Tin	0·002 „	..	0·002 „
Zinc	Rem.	..	Rem.

The specification was drawn up in this way as it was recognised that a very small pick-up of impurities in die-casting frequently occurs, despite the most stringent precautions to avoid it, and the wisdom of the policy has since been amply demonstrated. A recent Government specification for the manufacture of high-grade zinc alloy pressure die-castings has stipulated that no lead or tin materials shall be used in the same building as that in which zinc alloy die-castings are manufactured.

Measures such as the above have unquestionably raised the standard of zinc alloy die-castings in this country. Contamination and the resultant intercrystalline corrosion, causing cracking, distortion, and loss of strength, which did so much to place zinc alloy die-castings in disfavour, has been virtually eliminated, at any rate for Government stores. The benefits which have accrued from the steps taken during the war must inevitably yield a higher standard of zinc alloy pressure die-castings in the post-war years.

The single alloy which was selected for Government stores was Alloy A of B.S. 1004. While this is neither quite so strong nor so easily castable as Alloy B, it possesses greater dimensional stability and greater retention of impact strength after ageing or being subjected to elevated temperatures. These latter considerations, being of vital importance for such applications as fuse parts, outweighed the other small disadvantages.

In order to effect maximum conservation of raw materials, it was decided that any appreciable quantities of scrap or redundant zinc alloy die-castings should be remelted and made available in ingot form for further use. Accordingly, a British Standard Specification (B.S. 1141) was prepared and published in 1943, covering the manufacture of Secondary Zinc Alloy for Die Casting by the remelting of redundant castings which previously conformed to B.S. 1004. As many of the castings contained brass inserts, a large tolerance on the copper content is allowed, and the limits for the harmful impurities are higher than in B.S. 1004. The actual chemical composition of the secondary alloy ingot metal covered by B.S. 1141 is as follows :—

	%
Aluminium	3·9–4·3
Copper	1·0 max.
Magnesium	0·03–0·06
Iron	0·10 max.
Lead	0·007 „
Cadmium	0·005 „
Tin	0·005 „
Zinc	Rem.

It will be seen that as the copper content allowable is between nil and 1%, the alloy will vary in properties between those of Alloy A and Alloy B in B.S. 1004. Hence, neither the good dimensional stability and

permanence of properties of Alloy A nor the good castability and high tensile strength of Alloy B may be consistently expected. This fact, coupled with the higher permissible impurity contents and the possibility of inclusions due to remelting, means that the alloy should not be used for high-duty castings, but rather for lower grade work.

Zinc Alloy for Press Dies

Apart from die casting, the other large field in which the use of zinc alloy has rapidly expanded is that of dies for the forming and blanking of sheet metal for the aircraft industry. Originally, zinc alone was used for such dies, but as the requirements of the aircraft industry expanded with the forming of thicker and stronger material, zinc dies were found to be insufficiently strong. In their search for a stronger die material, an alloy of zinc with 4% of copper was used for a time by the aircraft industry in this country. The use of this alloy was again only transitory, however, for in the meantime it had been found that the zinc die-casting alloys of the type conforming to B.S. 1004, Alloy B, but containing even higher copper contents, were excellent die materials. As a result of experiments on these lines, an alloy called "K.M. Alloy" was evolved.

In the U.S.A. developments of a similar nature had occurred. Messrs. M. P. Kirk and Sons, Inc., after considerable experimentation with the existing die-casting alloys, modified the composition slightly and introduced an alloy known as "Kirksite A," which found immediate favour in the aircraft industry of the U.S.A. This alloy has played a large part in the prodigious aircraft production of that country.

K.M. alloy, like Kirksite, has been found to be an almost ideal material for forming dies, on account of its high compressive strength of 58 tons per sq. in. and its self-lubricating properties, which ensure that light alloy sheet is not scratched or damaged during the forming operations.

The alloy, which melts at 380° C., is cast into both open and closed sand moulds for the preparation of the dies. The most advanced technique for the preparation of dies for the forming of aircraft panels is as follows: a complete mock up of the particular section of the aircraft is made from plaster superimposed on a wire framework. The actual framework is built up from "loft templates" regularly spaced and connected together by wires running perpendicular to the templates and close to their edge. The plaster, suitably strengthened by muslin or similar material, is built up on these wires and rapidly smoothed to the contours outlined by the loft templates. The resulting mock-up, made in this manner, is permanent, and free from distortion or shrinkage. The mock-up is made to final dimensions except that it is made larger in all directions by an amount equal to the shrinkage of the zinc alloy (i.e., 0·14 in. per ft.).

To make a drop-hammer die to form sheet metal for any particular part of the mock-up, a plaster cast is taken direct from the mock-up. The plaster cast is then used as a pattern in the preparation of a sand mould for casting the tool.

Both punches and dies are now usually cast in zinc alloy. In the early stages of the development of the technique the punch was frequently made of antimonial lead, being cast directly into the zinc alloy die, which was made first. For forming the heavier gauge light alloy sheets, however, or for stainless steel, antimonial lead punches have been found too soft. Small zinc alloy punches may be cast directly into zinc alloy dies when the greatest dimension is, say, 1 ft. For larger punches, however, using this method, the shrinkage of the molten metal would render the punch too small, and a different technique is therefore adopted. This is as follows: The zinc alloy punch is cast first in a normal sand mould. It is then placed in a moulding box and suitably walled in. The punch is then coated with a protective wash, and the zinc alloy die-cast around it. In this way the shrinkage of the molten metal is on to the punch and not away from it.

Zinc alloy punches and dies are now used on all forms of drop-hammers, Cecostamps, hydraulic presses and stretching presses. The tools may be readily redressed or repaired by building up with molten metal, and when worn or obsolete they are merely remelted and used for casting further tools. They have successfully formed light alloy sheet as thick as $\frac{3}{16}$ in., and are in continual use forming 20 S.W.G. stainless steel for aero-engine exhaust systems. Fig. 2 shows a pair of K.M. alloy dies after producing 5,620 extremely difficult pressings in 20 S.W.G. stainless steel. The same manufacturer also uses zinc alloy for casting the many jigs and fixtures required in the assembly of the exhaust system. The life of well-designed tools forming 18–22 S.W.G. light alloy sheet is almost indefinite. Mild steel is, of course, very much more difficult to form, but a life of 18,000 pressings from 20 S.W.G. has been obtained. Stainless steel has been found most difficult of all to form, and the results achieved from the tools shown in Fig. 2 must be considered very satisfactory. Optimum results have been obtained with stainless steel pressings by the use of a pair of tools, the first rough-forming, the second giving the final strike.

Following the development in the U.S.A. of the use of rolled Kirksite for the construction of blanking dies, rolled K.M. alloy has been made available in this country and is being used with very great success. The rolled alloy is available commercially in sheets of size 6 ft. × 3 ft. × $\frac{3}{8}$ in. In this state the alloy has a Brinell hardness of 95–100, and is sufficiently soft to be readily cut by a bandsaw, yet is hard enough to maintain a cutting edge during blanking. The construction of the blanking tool, using rolled zinc alloy sheet, is briefly as follows:—The punch is made first from steel and is finished to the final dimensions of the blank required. The punch is then clamped to a sheet of K.M. alloy, and its contours scribed thereon. The zinc alloy inside the scribing is then removed either by means of a bandsaw or in a routing machine. The orifice in the zinc alloy sheet is, however, made approximately $\frac{3}{64}$ in. smaller all round than the punch, and the edge of the impression is frequently undercut by bevelling. The punch and die are now mounted on steel backing plates and lined up by dowel pins and sockets. The partially completed tool is then mounted in a press, and using the full force of the press, the steel punch is used as a broaching tool and forced through the zinc alloy. This operation produces a perfect shearing edge on the zinc alloy die and the tool is now ready for use. Ejection of the blank is brought about by cementing strips or circles of hard rubber inside the die, and the scrap is similarly stripped off the punch by rubber cemented around it.

Blanking tools made by this method may be constructed in a fraction of the time taken to make the same tools in steel. It will be seen that even if one zinc alloy

die is spoiled, if the punch is still satisfactory, it is a very rapid task to cut out and broach a new zinc alloy die. There are also other simple devices to extend the life of the die. For instance, if the cutting edge becomes worn, it may be tapped back to shape by hammering, or the top of the die containing the worn edges may be machined off in a shaping machine, or, again, the zinc alloy die may sometimes be inverted and rebroached again from the bottom. Naturally, the maximum economy is only attained from this method of tooling when large blanks are required. The method is also not intended for long runs, but is ideally suited when only a small or medium number of blanks is required.

In the U.S.A., 30,000 blanks of 21 S.W.G. duralumin have been obtained using this method. In this country, where such long runs have not been required, 5,000–6,000 blanks have been produced in up to 16 S.W.G. duralumin or Alclad without any deterioration in the quality of the blank. It has been estimated that these dies could have produced 15,000 blanks before the die would require attention. Fig. 3 shows a blanking and piercing die in K.M. alloy made by the Bristol Aeroplane Co., Ltd.

The method must naturally be used cautiously for the blanking of steel. 3,000 blanks have been obtained in this country from 22 S.W.G. mild steel, and 500 in 18 S.W.G., both sets of blanks being of a high quality; no attempt was made during these runs to take the die to destruction to determine the maximum number of blanks which could be obtained, at the expense of the quality of the blank.

Moulds for Plastic Moulding

A further development during recent years has been he use of zinc alloys for the casting of moulds for plastic moulding. Here similar advantages accrue as with the drop-hammer dies—namely, ease of casting and working and complete reclamation of obsolete or worn dies. In addition to casting the moulds, American manufacturers have also shown that deep cavities can be hobbed in a cast alloy blank, provided the latter is heated to 175° C. A new zinc alloy has also been developed in the U.S.A. for the die-casting of tyre mould segments for rubber tyre moulding.

Conclusion

In the foregoing article an attempt has been made to outline the chief uses and applications of zinc and zinc alloys largely during the war-time years. The return of peace will see an inevitable redistribution of supplies and methods, and the picture as presented above will be somewhat modified. It is anticipated, for instance, that pre-war production of zinc alloy die-castings will be greatly exceeded, as the experience gained during the war by the die-casting industry in meeting the critical requirements of the Services will create a higher standard of castings generally which was not available before the war. A greater use of sheet zinc by the building trade for roofing and other purposes is also foreshadowed, and the removal of the restrictions on galvanising will inevitably result in a large increase in the use of galvanised sheet and articles of all types, which have been so greatly missed during the war years.

In conclusion, the author wishes to thank the Imperial Smelting Corporation, Ltd., for their assistance in the preparation of this article.

Better Bronze for Industry

BRONZE with greatly increased strength and toughness can be made from common grades of tin and copper without the purchase of new or special equipment. Ths process is the result of several years of research, and ie now disclosed in the two recent publications of the Tin Research Institute, Nos. 120 and 121. Both are reprints from the *Journal of the Institute of Metals*.* In the former, Dr. W. T. Pell-Walpole describes the development of a flux degassing process which enables tin bronzes and phosphor bronze to be produced successfully from ordinary commercial grades of metal, or from scrap, where previously high-grade metal was essential. This is achieved by using a simple flux containing borax, sand and copper oxide. Bronzes containing 10% tin, suitably cast, can be extruded and subsequently cold-rolled and cold-drawn. For example, a 10% tin phosphor-bronze gave 24 to 28 tons per sq. in. tensile and 10 to 20% elongation in 2 in. The specification of the comparable commercial alloy (2B8) calls for only 16 tons tensile and 1·5 to 4% elongation.

Bronzes with 10 to 14% tin, when made by the new method, can be hot- or cold-rolled, and the wrought products have exceptional mechanical properties. A 10% tin bronze, extruded and cold-rolled, gave 75 tons tensile with 18% elongation.

The method of casting giving the maximum tensile and rolling properties is described by Drs. W. T. Pell-Walpole and V. Kondic in the second publication. In th is the authors show that variation in casting procedure has a considerable effect on the quality of degassed chill-cast 10% tin bronze. By adopting the procedure recommended, a bronze which can be extruded, hot-rolled, forged or hot-stamped is readily obtained. Such bronze will meet many long-felt needs in the engineering world, and bronze bars or strip which can be worked up to 75 tons tensile and yet retain their toughness provide what is virtually a new product with a wide potential field of usefulness.

Only limited numbers of these reprints are available, but copies may be supplied on application to the Tin Research Institute, Fraser Road, Greenford, Middlesex.

* Vol. 70, 1944, pp. 127–147 and 275–289 respectively.

Specification of Meehanite Metal

THE above is the title of a booklet recently issued by the International Meehanite Metal Co., Ltd. Essentially, it has been compiled to provide a guide to the physical properties of the various types of Meehanite Metal, which is the trade name of a number of cast irons produced by controlled processes, providing castings possessing properties that meet the broad requirements of the engineering industry.

First issued about two years ago, the opportunity has been taken to introduce some changes in this second edition, which experience has shown to be desirable. Copies may be had on application to the International Meehanite Metal Co., Ltd., 66, Victoria Street, London, S.W. 1.

Progress in Research Methods in the Metallurgy of Cast Iron with Special Reference to Gases in Cast Iron

By J. E. Hurst, D.Met.

(*Technical Director, Bradley & Foster Ltd.*)

Much of the information on cast iron, on which engineers and designers base their calculations, has been made obsolete by recent advances in the manufacture of castings. To-day greater dependence is placed on scientific production control, and when difficulties are encountered the fuller knowledge available permits a thorough investigation with the object of determining the cause and so enabling the difficulties to be overcome. It is, therefore, opportune to discuss progress in research methods in relation to a recurring problem experienced in the iron foundry.

THE foundry problem of variation in character or quality of castings produced from apparently the same materials is one which has been discussed and speculated upon for many years. In many cases of this sort the foundryman and metallurgist has postulated the existence of intrinsic or inherent qualities or properties in the iron he uses, the causes of which have as yet not been explained. The suggestion that, in some cases, they are attributable to the material and methods from and by which the original pig iron was produced has resulted in this matter being discussed under the title—heredity in pig iron. It can be well understood that this subject is one which has attracted research workers continuously, and on which developments in research methods may be expected to throw additional light.

A foundry producing continuously a particular casting by uniform mechanised methods, involving modern methods of sand preparation and metal melting control, experienced, at irregular intervals over a number of years, epidemics of porosity which were revealed on submitting the castings to hydraulic test. The foundry also observed that consignments of pig iron to their specification varied in character. Sometimes the iron was noticeably more easy to break and when this happened invariably showed a slightly more open-grained fracture. The further observation was made which appeared to connect up the epidemics of unsoundness with this variation in the pig iron, it becoming clear to the practical foundryman that the particular unsoundness in the castings arose only when the more easily broken variety of iron was used in the mixture. This is a very brief description of a set of circumstances which appeared to offer an excellent opportunity to undertake a complete investigation to ascertain how far the observed differences could be accounted for.

The specimens obtained for the purpose of the investigation consisted of examples of the pig irons showing the differences in character reported and specimens of the castings, the completely sound, and the castings showing porosity. The importance of securing satisfactory samples and specimens in relation to an investigation is of fundamental importance in research methods and no trouble is too great with this end in view. The facilities available to the modern metallurgist in the shape of cutting and milling machines, slitting saws, bench grinders, surface grinders and magnetic chucks, are so commonplace now that it is difficult to imagine the tedious, laborious and often ingenious methods by which specimens were obtained 30 years ago, when such aids were the exception.

An investigation of the type visualised, and indeed almost any metallurgical investigation, requires the determination and comparison of the composition, constitution and physical and mechanical properties of suitably chosen specimens.

Composition

The composition of cast iron is assessed normally by the determination of the carbon (total, graphitic and combined), the silicon, manganese, sulphur and phosphorus. The influence of alloying elements is now recognised, and a good deal more is known about their influence than was known 30 years ago. Such additional elements may be present in a modern cast iron either as a deliberate addition or as residual elements arising from the raw materials used in the production of the pig iron or the mixture used in the production of the castings. In investigations connected with cast iron to-day it is becoming of increasing importance to consider the presence of additional elements. The most common and most likely are nickel, chromium, copper, molybdenum, vanadium and titanium. Aluminium and zirconium may be present as deliberate additions, and boron and tellurium are elements the presence of which in very small quantities is known to have a profound effect upon the condition of the carbon. Arsenic and tin may be present as residual elements, and are recognised as having an effect upon the constitution of cast iron. This list can be extended further when it is remembered that ladle additions, such as calcium silicide and ferrocerium are used, and cobalt and tungsten are not unlikely to be present even as residual elements. It will be understood that in any complete investigation into any hitherto unexplained behaviour of cast iron the presence or absence of all these additional elements must be determined. The formidable character of the task of the determination of the existence of these elements in a specimen under investigation let alone their estimation can only be realised fully by those who have attempted it. The complete analyses of the sound and unsound castings referred to are given in Table IA/B. In this table the chemical estimation of the normal elements is reinforced by the spectrographic determination of the presence of additional elements together with the check estimation by spectrograph of certain of the elements

present. The actual results show no significant difference in composition, nor do they reveal the presence of any abnormal element which might be expected to help in explaining the difference in character of the two castings.

The value and importance of spectrographic analysis in investigation work of this kind will be apparent from these results. How easily and quickly could we have settled some of the speculations of 25 years ago had we had available the modern spectrographic equipment, comparator, photometer, and the present-day technique in the production of photographic emulsions.

The development of spectrographic methods of analysis are by no means the only advance in research methods in the determination of the composition of metallurgical materials. There are many improvements in laboratory apparatus. Weighing apparatus, heating apparatus, temperature measurement, the use of the photo-cell in colorimetric measurement have improved in accuracy, precision and reliability.

Constitution

Under this heading I am able to deal with the examination of cast iron under the microscope. The constitution as revealed by the micro-structure of specimens from the castings referred to in Table I were compared, and also compared with specimens cut from the samples of pig iron. In the Figs. 1 to 16, which follow, specimens from the thick and thin portions of the castings and from the centre and edge of the pig irons have been photographed, and for comparison purposes are best studied in groups of four as follows :—

Fig. 1.—Outside edge of close-grained pig iron ..... × 120 diam.
„ 2.—Outside edge of open-grained pig iron ..... „
„ 3.—Thin portion of sound casting ..... „
„ 4.—Thin portion of unsound casting ..... „
„ 5.—Outside edge of close-grained pig iron ..... × 600 diam.
„ 6.—Outside edge of open-grained pig iron ..... „
„ 7.—Thin portion of sound casting ..... „
„ 8.—Thin portion of unsound casting ..... „
„ 9.—Centre of close-grained pig iron ..... × 120 diam.
„ 10.—Centre of open-grained pig iron ..... „
„ 11.—Thick portion of sound casting ..... „
„ 12.—Thick portion of unsound casting ..... „
„ 13.—Centre of close-grained pig iron ..... × 600 diam.
„ 14.—Centre of open-grained pig iron ..... „
„ 15.—Thick portion of sound casting ..... „
„ 16.—Thick portion of unsound casting ..... „

These photo-micrographs reveal an interesting similarity between the structure of the castings and the pig irons used in the mixture. The dendritic nature of the thin section of the unsound casting (Fig. 4) may be compared with a similar appearance of the outside edge of the open-grained pig iron (Fig. 2). The structure of the sound casting and close-grained pig iron did not show this feature very marked (cf. Figs. 3 and 1). In the thick sections of the two castings the unsound casting showed a coarser type of graphite (e.g., Figs. 12 and 11), and this is in line with the appearance of the close and open-grained pig irons (cf. Figs. 9 and 10). In the thin sections the graphite size was practically the same in both sections. Reviewing these photographs as a whole, the metal of the faulty casting showed a difference in structure amounting to a more marked dendritic character in the thin sections and a greater difference in graphite size and possibly grain size between the thick and thin sections. These structural differences are definitely similar in character to the structural differences in the pig irons and the conclusion must be reached that either by chance or design the structural character of the pig irons has been retained in the castings.

The progress of the technique in the micro-examination of cast iron is outstanding in any review of research methods applied to cast iron. If any evidence of this

Fig. 1.—Outside edge of close-grained pig iron. × 120

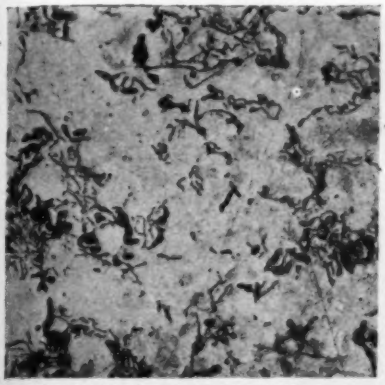
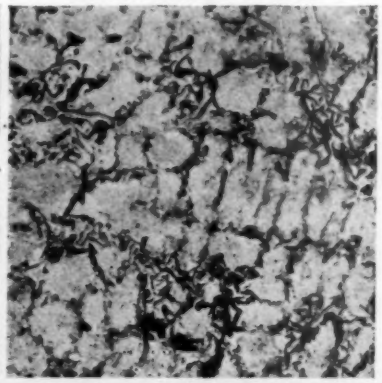


Fig. 2.—Outside edge of open-grained pig iron. × 120.



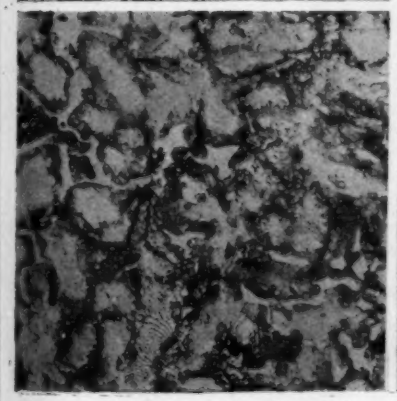


Fig. 3.—Thin portion of sound casting. × 120.

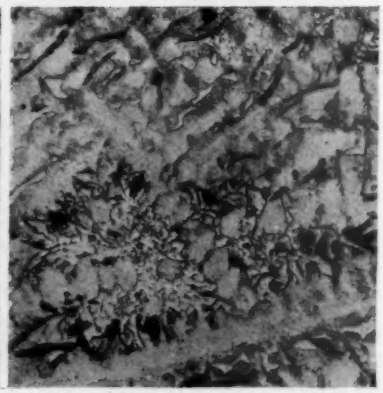


Fig. 4.—Thin portion of unsound casting. × 120.

TABLE Ia.
CHEMICAL ANALYSIS OF CYLINDER IRONS.

	Unsound Cylinder.	Sound Cylinder.
TC	3·35	3·26
GC	2·75	2·63
CC	0·60	0·63
Si	1·73	1·90
S	0·068	0·062
P	0·26	0·32
Mn	0·85	0·85

TABLE Ib.
SPECTROGRAPH ANALYSIS OF CYLINDER IRONS.

	Unsound Cylinder.	Sound Cylinder.
Si	1·73	1·90
Mn	0·85	0·83
Ni	0·72	0·68
Cr	0·30	0·28
Mo	0·02	0·02
W	A	A
V	A	A
Ti	A	A
Co	A	A
Cu	0·05	0·04
Al	A	A
Zr	A	A
Sn	A	A
Pb	A	A
As	A	A
Zn	A	A
Ag	A	A

A equals Absent—i.e., less than 0·01%.

is deemed necessary, a comparison of present-day photo-micrographs of cast iron with many of those of 25 years ago will show at once that the improvement is startling. There has, of course, been very great progress in the mechanical, optical and illuminating equipment of the microscope which make light of the task of micrographic observation, both in quality of the results and in speed.

Nor must the very great improvements in photographic materials be overlooked, and their value and usefulness in recording in for greater detail, and more faithfully, the observations revealed.

But in so far as cast-iron metallurgy is concerned, even these improvements take second place when considered alongside the improvement in the technique of the preparation of cast-iron specimens for examination. This improvement received its greatest impetus, and can be considered to be due to the work of the British Cast Iron Research Association. The technique worked out by them and described byMorrogh[1] has not only been responsible for the vast improvement in photo-micrographs of cast iron, but has made it possible for us to actually see and to understand still more the nature and form of the graphite phase and others of the important phases responsible for the characteristics of cast iron. No photo-micrograph of grey cast iron to-day not clearly showing the graphite constituent in itself should be accepted as satisfactory.

If there are any who think the microscope has outlived its period of usefulness in face of the developments in X-ray diffraction technique, the electron-microscope and electrical and magnetic methods of investigation, they should refer to the further work of the B.C.I.R.A. and Mr. Morrogh on the identification of minor phases in cast iron,[2] and the skill and ingenuity in the adaptation of the microscope and polarised light to this purpose.

Mechanical Properties

Thirty years ago the determination of the hardness of cast iron was the subject of much discussion and the rival merits of drilling tests, scratch tests, the scleroscope, which had just been developed, and the Brinell test were widely debated. The Brinell test, now that it is more properly understood, together with diamond penetration hardness tests, are in common use to-day, but were then looked upon with considerable suspicion. Apart from the Brinell test, using different diameter balls and loads, we have available to-day the scleroscope, the Rockwell, and the diamond hardness tests, such as the Firth Hardometer and the Vickers' hardness testing machine. The very great value of these methods of hardness testing has been recognised in all the investigation work that has been done in the field of cast-iron metallurgy over recent years.

In the investigation of the two castings under discussion the Vickers diamond hardness values were taken at a number of points across a polished section from each of the castings. The hardness exploration across the wall thickness of the castings is illustrated in Fig. 17, from which it will be seen that little change in hardness occurred from the outside to the inside of the casting. The two castings did not vary appreciably in average hardness, being 225 and 227 V.P.N. in the faulty and sound casting respectively.

For the determination of the ultimate breaking strength in tension, compression or transverse bending, many improvements have been introduced in the design of testing machines. For research purposes the application of special machines or methods, such as the ring-testing method as used for piston rings, or the Hounsfield Tensometer, enables comparisons of the mechanical strength properties to be made on small specimens cut from samples under investigation, which are of such sizes and shapes as to be incapable of yielding test-pieces of sizes corresponding to the test-piece dimensions which are given in accepted specifications.

In the case of the two castings under investigation, the breaking strengths were determined as moduli of rupture using square test-pieces machined out of the castings and tested in duplicate on the Hounsfield

Fig. 5.—Outside edge of close-grained pig iron. × 600.

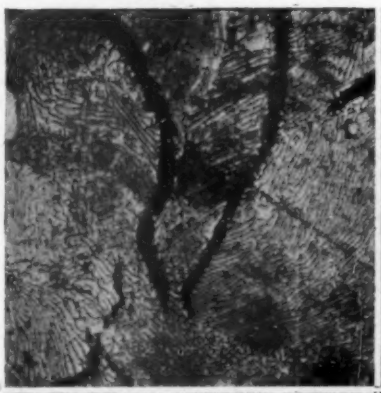
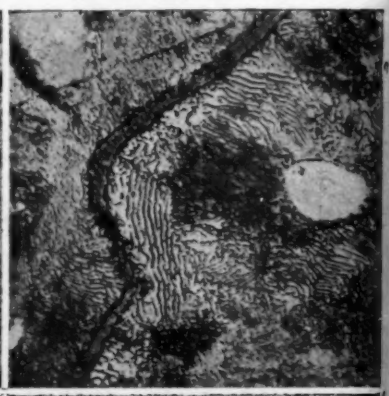


Fig. 6.—Outside edge of open-grained pig iron. × 600.



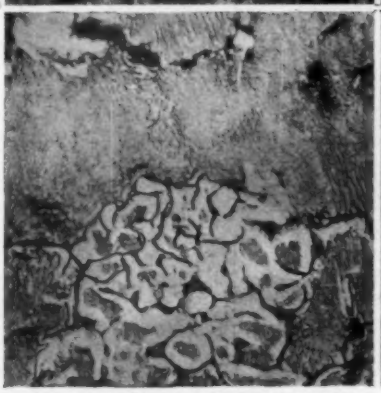


Fig. 7.—Thin portion of sound casting. × 600.

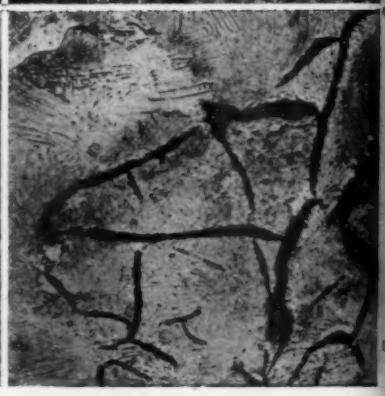


Fig. 8.—Thin portion of unsound casting. × 600.

1 Morrogh. *J.I.S.I.*, No. 1, 1941.
2 Morrogh. *J.I.S.I.*, No. 1, 1941.

Tensometer. The results obtained were as follows :—

Faulty casting.....	32·8 and 32·0 tons per sq. in.
Sound casting	33·9 and 32·0 " "

As in the case of the diamond hardness values, no appreciable variation in the ultimate breaking strengths as moduli of rupture was disclosed in the two castings.

These two castings, therefore, one of which is sound and the other unsound, are practically identical in composition, in hardness and strength properties. They differ in micro-structure, and this difference bears some resemblance to the differences in micro-structure of the pig irons used in the mixture.

A further avenue remained to be explored in this search for some difference which might help in the understanding of this behaviour—viz., the gas contents. Although this might have been considered under the heading of composition it is considered advisable to deal with it as a separate section. The gas contents of the specimens determined by the vacuum fusion method are given in Table II.

A difference in the gas contents is revealed by these results. The unsound casting has a higher hydrogen content and a lower oxygen and nitrogen content than the sound casting. More significant still is the fact that the gas contents of the castings correspond to the gas contents of the pig irons, and not only is there a similarity in the graphite distribution and structural character, but this extends to the gas contents of the two samples of pig iron and castings.

Fig. 9.—Centre of close-grained pig iron. × 120.

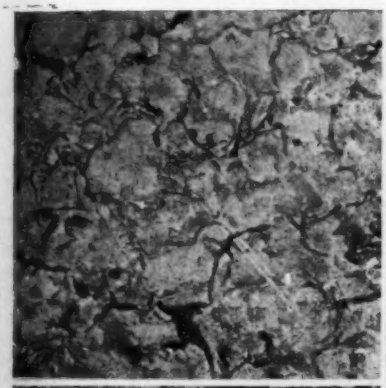


Fig. 10.—Centre of open-grained pig iron. × 120.

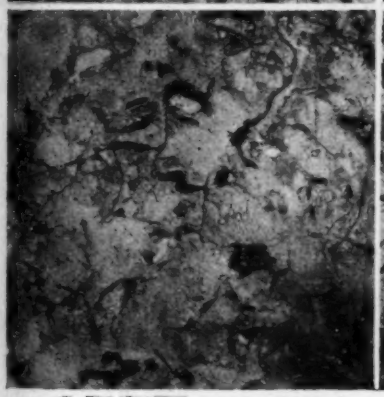


Fig. 11.—Thick portion of sound casting. × 120.

Fig. 12.—Thick portion of unsound casting. × 120.

TABLE II.
VACUUM FUSION DETERMINATIONS OF OXYGEN, NITROGEN AND HYDROGEN IN THE CAST-IRON SPECIMENS.

Sample.	Quality.	Oxygen, %.	Nitrogen, %.	Hydrogen. Mls. per 100 grms.
Refined pig iron	Open fracture	0·004	0·004	4·7
	Close-grained	0·011	0·005	3·8
Cylinder castings	Leaky	0·003	0·004	4·2
	Sound	0·011	0·005	3·7

TABLE III.
VACUUM FUSION DETERMINATIONS OF OXYGEN, NITROGEN AND HYDROGEN IN A NUMBER OF SILICON IRON ALLOYS.

No.	Condition of Sample.	Oxygen, Wt. %.	Nitrogen, Wt. %.	Hydrogen, Mls per 100 grms.
1.	Very porous } arranged in order of porosity.	0·0110	0·0027	5·05
2.	" " }	0·0190	0·0042	10·08
3.	Porous }	0·0100	0·0040	6·99
4.	Very porous	0·0117	0·0041	10·5
5.	Sound castings	0·0011	0·0036	1·96
6.	" "	0·0008	0·0028	1·94
7.	" "	0·0010	0·0034	1·71
8.	" "	0·0009	0·0037	1·40

The view may be taken from this investigation as far as it has gone that these results tend to confirm the foundry observations of a difference in character between the sound and unsound castings, and that these are probably a reflection of the differences in character of the pig irons used in the metal mixture. The investigation has also succeeded in tracking down differences in gas contents which may possibly be of assistance in accounting for the observed differences in characteristics of the castings.

In attempting to partially deal with the question of how far results of this type can be used in accounting for differences in foundry behaviour, results from certain other investigations can be considered. These concern studies that have been made into the factors affecting the soundness of castings in an alloy containing 14 to 16% of silicon—the acid-resisting silicon iron alloy.[3] The greatest single trouble in the production of sound castings in this alloy arises from the dissolved gas content, and investigation shows that the principal gases present are oxygen, nitrogen and hydrogen.

TABLE IV.
VACUUM FUSION DETERMINATIONS OF OXYGEN, NITROGEN AND HYDROGEN IN RAW MATERIALS USED IN THE MANUFACTURE OF SILICON IRON ALLOYS.

No.	Raw Material.	Oxygen, Wt. %.	Nitrogen, Wt. %.	Hydrogen Mls. per 100 grms
1.	Dry steel scrap, Sample A	0·0087	0·0041	0·78
2.	" " " B	0·0090	0·0041	0·80
3.	Rusty, wet steel scrap, Sample C	0·012	0·0037	6·00
4.	Canadian ferro-silicon, 45% A	0·016	0·0006	8·1
5.	" " " B	0·013	0·0014	9·5
6.	" " " C	0·017	0·0010	9·0
7.	" " 75% A	0·021	0·0053	8·7
8.	" " " B	0·036	0·0031	9·3
9.	" " " C	0·028	0·0041	9·2
10.	" " " D	0·022	0·0055	8·7

[3] J. E. Hurst. "Improvements in Manufacture of Silicon-Iron Alloy. Inst. of Chemical Engineers, 1944.

Some of the oxygen present was found to exist as carbon-monoxide, and the results of the experiments show that gas porosity in the castings is due to the combined effect of this gas and hydrogen, hydrogen being the primary cause. The volume of carbon-monoxide submitted to fractional vacuum fusion experiments was of the same order as the volume of hydrogen. The results in Table III show the amounts of gas found by the vacuum fusion method in a number of specimens as described. The total volume of gas extracted from a porous specimen depended somewhat upon the degree and type of unsoundness. As in the case of examples 1 and 3 in Table III, a badly "blown" casting might yield less hydrogen than one obviously sounder. Results of this type are regarded as being due to the loss of gas from sealed pores during crushing for sampling. The results, however, clearly show that in this alloy sound castings invariably had a hydrogen content not greater than 2 mls. per 100 grms., and a hydrogen content in excess of this is invariably associated with visible unsoundness in the castings.

It is of interest to follow some of the investigations into the sources of hydrogen in the metal.

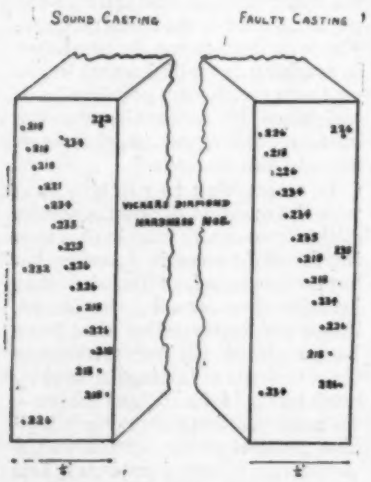
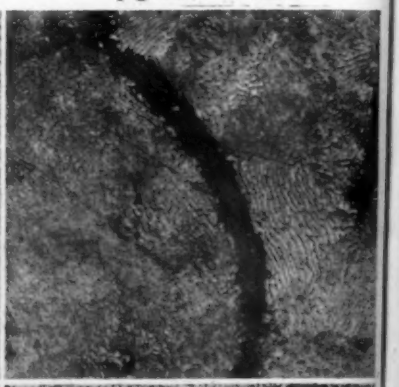


Fig. 17.—Hardness exploration across the wall thickness of the castings.

grms., but when rusted it could contain up to 6 mls. per 100 grms. Two grades of ferro-silicon each had a hydrogen content of 9 mls. per 100 grms. Using clean dry materials based upon the proportions present in the mixture, a calculated maximum of 3 mls. per 100 grms. of hydrogen might be present in the charge, an excess over the maximum acceptable amount of 2 mls. per 100 grms. revealed by our investigations. In addition to hydrogen available from this source, the possibility of hydrogen absorption from damp furnace or ladle linings and improperly dried moulds is another potential source. Table V records a selection of gas content determinations on specimens designed to reveal any influence of the condition of the furnace and ladle linings, and these are shown to have a

Fig. 13.—Centre of close-grained pig iron. × 600.

Fig. 14.—Centre of open-grained pig iron. × 600.



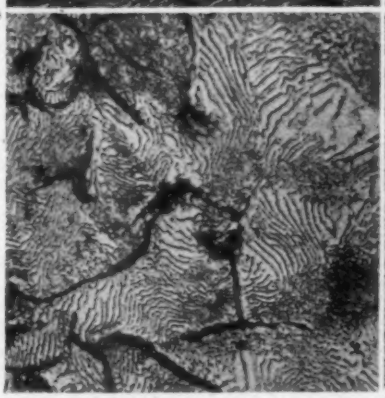


Fig. 15.—Thick portion of sound casting. × 600.

Fig. 16.—Thick portion of unsound casting. × 600.

In Table IV are given the results of the vacuum fusion determinations of the raw materials used in the manufacture of this alloy. Clean dry steel scrap, one of the chief raw materials had a hydrogen content of 1 ml. per 100

TABLE V.

VACUUM FUSION DETERMINATIONS OF OXYGEN, NITROGEN AND HYDROGEN, SHOWING INFLUENCE OF CASTING CONDITIONS ON SILICON IRON ALLOYS.

No.	State of Furnace.	State of Ladle.	Oxygen, Wt. %.	Nitrogen, Wt. %.	Hydrogen Mls. per 10 grms.
1.	Dry	Damp lining	0·0024	0·0033	3·3
2.	Newly patched	Dey	0·011	0·0027	5·05
3.	" "	"	0·019	0·0042	10·08
4.	" "	"	0·010	0·0040	6·99
5.	Dry	Patched lining	0·0030	0·0040	3·07
6.	"	Dry	0·0039	0·0021	2·79
7.	"	"	0·0026	0·0011	1·87
8	"	"	0·0053	0·0024	2·76

profound effect. For example, a ladle lining was patched with wet refractory cement and allowed to dry at a temperature of 200° C. overnight. The next morning exactly similar metal was cast from this ladle and from one thoroughly baked free from combined moisture by holding in it previously a hot metal charge. From the first ladle porous castings were obtained, showing a hydrogen content of 7 mls. per 100 grms., whereas from the other sound castings were obtained in which the hydrogen content was 1·7 mls. per 100 grms.

These results drawn from other investigations show more clearly the importance of the dissolved gas content and how very likely it is that results of this type will play a part in accounting for the differences in behaviour of irons in the foundry. The investigation described ha

produced evidence which points very strongly to the fact that—

(*a*) The difference in characteristics of the castings examined is associated with the dissolved gas content.

(*b*) The difference in characteristics of the two pig irons is associated with the dissolved gas content.

(*c*) The difference in characteristics of the pig iron associated with the dissolved gas content survive the remelting and casting procedure in the foundry.

Further work is necessary to establish the general influence of dissolved gases on the properties of cast iron and to provide an understanding of how their influence is brought about. In so far as dissolved gases may be regarded as part of the composition of cast iron, the possibility of their reliable determination must be included in the list of powerful research methods available to the metallurgist to-day.

A Producer Gas-Fired Furnace Installation for the Heat-Treatment of Alloy and Special Steel Bars

In recent years considerable attention has been given to the use of producer gas for heat-treatment furnaces, and by courtesy of the Hallamshire Steel and File Co., Ltd., particulars are given of an installation for the heat-treatment of alloy and special steel bars which is fired with producer gas.

A COMPLETE installation for the heat-treatment of steel bars and sections has recently been designed and built by Incandescent Heat Co., Ltd., and has many interesting features. The plant comprises four heat-treatment furnaces, two oil quenching tanks, one water-quenching tank, four loading platforms, and an electrically operated wedge type high-speed charging machine.

The plant is designed for a continuous output, in either hardened and tempered, annealed or normalised conditions, of alloy and special steel bar and section stock, sizes from ½ in. to 6 in. diameter, or equivalent area in squares, flats, hexagons, octagons and other sections. Facilities are provided for oil and water quenching and tempering.

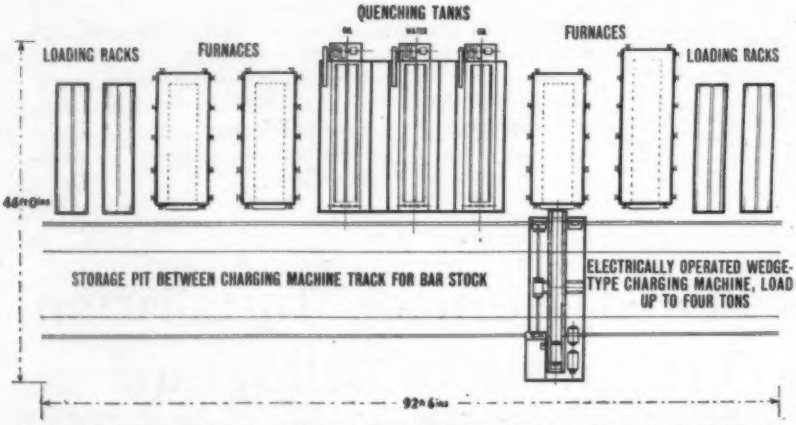
The use of continuous furnaces for prolonged treatment cycles would have been somewhat at a disadvantage as their dimensions would necessarily be of unwieldy proportions to permit an output figure consistent with economic operating conditions. It was therefore found advisable to revert to use of batch type furnaces, which, when operating with the assistance of mechanical handling equipment, give very uniform results, and leave little to be desired in regard to quality, quantity and performance.

The bulk of the stock was such that storage facilities must be found adjacent to the furnace plant to accommodate both untreated and treated materials, and the construction of a deep pit between the track of the charging machine provided adequate storage accommodation (approximately 400 tons), thereby permitting a continuous flow so vital for uninterrupted outputs.

General view of the complete installation.

Batch type furnaces and mechanical charging and quenching equipment have been used to the best possible advantage in this heat-treatment installation, and have proved beyond doubt the ability of such a layout to maintain consistently high rates of output. As can be seen from the illustrations, the use of mechanical handling equipment enables female labour to deal with heavy loads of material quickly and easily.

The furnaces are of the incandescent recuperative under-fired natural draught type, operating on clean producer gas. Three have inside dimensions 14 ft. long by 3 ft. wide by 2 ft. high, and one has inside dimensions 17 ft. long by 3 ft. wide by 2 ft. high. The burners fire into individual combustion chambers below the hearth,



Layout drawing, showing location of furnaces, quenching tanks, loading racks, etc. The storage pit will accommodate approximately 400 tons of stock.

where the gas and preheated air is thoroughly admixed and combustion takes place before the gases are drawn into the heating chamber. The waste gases are drawn into the deep recuperative system built below the hearth for preheating the secondary air. Counter-balanced doors operated by a geared hoisting mechanism provide easy means of opening and closing the furnace aperture. Best quality refractories are used for lining the furnace chambers, recuperators, etc., and a backing of insulating material reduces heat losses to a minimum.

Quenching

After being conveyed to the quenching tank by the wedge-type charging machine, the charge is placed on a table, which is lowered into the quenching medium by means of wire rope suspension from overhead drums driven by motor reduction and chain gear. The movement is push-button controlled in conjunction with limit switches. A special safety device is incorporated in front of each tank to prevent the load being run over the tank before the receiving table is in position. Quenching oil is maintained at a pre-determined temperature by a circulating system incorporating a special water-cooled oil cooler.

The method of lowering the load of bars into the oil in a fixed time has this advantage—during the whole loading operation fresh oil is being constantly brought into contact with the load, not only by convection currents set up during cooling, but also by the steady mechanical motion of the work through the oil. If necessary, the load can be given a reciprocal motion through the oil, after it has reached its lowest point in the quenching tank, simply by suitable manipulation of the control buttons.

Electrically Operated Charging Machine

An interesting feature of the installation is the electrically operated two-fork wedge-type charging machine, which has been specially designed for the rapid movement of heavy loads. The charging forks have a total forward reach of 16 ft., and carry an evenly distributed load of 4 tons of bars.

The rapid handling of the load is an essential feature of the heat-treatment, and this machine is exceptionally fast, being capable of charging, or discharging, a full load in a few seconds. It will travel along a shop at a maximum speed of 250 ft. per min.

The operation of the machine is controlled electrically throughout. The raising and lowering of the forks is effected by means of specially designed rollers and wedge-shaped cams, in conjunction with a cross-head and screw, driven by electric motor through reduction gear. The drum controller incorporates suitable automatic stop mechanism, when the load is raised or lowered to eliminate any dependence upon the human element.

The forks of the machine are provided with heavy duty rollers for running in along the hearth of the furnace at the bottom of the charging slots, and a separate motor reduction gear and twin chain drive operates the forward and reverse movements, in conjunction with limit switches. Because of the heavy loads handled by the machine the running-in motion is controlled by a specially designed resistance drum controller.

All the controls for operating the machine are located together within easy reach of the operator, who stands on a platform at the rear of the machine. The complete machine is designed for attaining the maximum speed of operation, in conjunction with simple, effective and instantaneous control, and these features considerably help towards the successful operation of the complete furnace installation by means of female labour.

Two Incandescent Gas Producer Plants, each capable of generating 20 therm of clean producer gas per hour.

Reviews of Current Literature

Recommendations for Uniform Cost-Estimating and Cost-Finding for the Drop-Forging Industry

ACCURATE costing in the drop-forging industry has always been a difficult problem for the estimator, and only to a slightly less extent to the cost-finder in the accountancy department of a firm. So many variable factors are involved in the production of drop-forgings that costs on a comparable basis throughout the industry are not easy to attain. This fact has, for a long time, been recognised by the Executive Committee of the Drop Forgers' and Stampers' Association, and in 1943 a committee, known as the Costing and Standardisation Committee, was appointed to study the problem, and the results of their deliberations are set out in this book.

Obviously, past experience in the production of similar forgings is of great practical value in estimating, but such experience will not always suffice to cover the problems with which the estimator is confronted in considering entirely new types of forgings, involving possibly closer tolerances, finer finish, and higher ranges of production, not to mention the difficulties which may be met following upon the introduction of new specifications or variations in existing ones. It is necessary, therefore that complete details be set out on the estimate form, not only to serve as a means of quotation for any specific drop-forging, but to be of practical service in production should the firm be successful in securing the order. The preparation of an estimate must proceed through a number of stages, and this data, together with any other particulars relating to a particular job, should appear on the estimate form. This has been customary for each forging manufacturer, but the design of the estimate form used has been built up individually, with the result that wide variation exists in compiling estimates and in the prices quoted.

The Committee has made a careful study of various estimating used by members of the Association, and recommend the general use of a form of estimate, shown in Appendix I, for adoption through the industry. It is claimed that the general use of this form will help to achieve uniformity in estimating practice and will ensure that none of the elements of cost is omitted.

The two functions of costing—viz., cost-estimating and cost-finder—form the two sections of the book. The former is concerned primarily with the recommended estimate form. It describes the individual element which progressively build up the estimate and also provide the working data ; thus, it is concerned with material, weights, American practice in weight determination, price, material handling, forge furnacing, setting-up, hammer piecework prices and labour cost, national bonus, overheads, treatment, hardness and tensile tests, dies and tools, die life, warehousing and transport, customers' rejects, etc.

The section on cost-finding deals with elements of cost, cost references, and the use of classified coding symbols, materials, labour, overhead expenditure, forge furnace, heat-treatment and other process costs, collection and recording of costs, and cost ledger.

The Committee is to be congratulated for the care taken in presenting lucid information on the subject, especially for the twelve Appendices which, in addition to the recommended estimate form, include recommended forms for preparing detailed information, such as estimate of labour and overheads for dies and tools, summary of accounts classification, departmental and operational coding symbols, expense coding symbols, direct labour operations, die-shop operations, overheads schedule, costs collection and recording chart, job cost card, summary of dies and tools cost, and also a detail sheet for dies and tools cost.

The proposals presented in this book are worthy of the closest attention of those engaged in the production of drop-forging ; their acceptance would do much to remove any suspicion between one manufacturer and another, and permit the healthy competition of efficiency. The book is admirably produced, and should quickly be recognised as the standard work on the costing of such complex products as drop-forgings.

Published by the Association of Drop Forgers and Stampers, 45, Newhall Street, Birmingham 2.

Post-War Planning and Anglo-American Economic Relations

IN view of the intense interest in export matters, this report on practice and opinion in British industry during the current year should receive the careful attention of all business men who are in any way connected, or contemplate being associated with, export trade. The survey on which the report is based was undertaken to find out what British industrialists and commercial leaders were doing and thinking about planning for post-war industrial operations, and in particular about future Anglo-American economic relations.

The instrument chosen for the survey was a questionnaire issued and returned by post. The objections which are sometimes valid against the use of a postal questionnaire were believed to be outweighed by the advantages in this case. While a spontaneous response was sought, it was recognised that some care and thought—and time—would need to be devoted to the questions before they could be answered, and that in such circumstances personal interviews would be unsuitable. In the course of the conduct of the survey, however, many personal discussions of the issues involved have served to illumine and expand the thoughts expressed in written answers.

The purpose of this report of the survey is twofold :—

1. To give an impartial picture of what British industrial and commercial organisations are doing about post-war planning and what difficulties and obstacles interfere with this objective.
2. To give an impartial picture of what British business men think about Anglo-American economic relations after the war.

It is not suggested that the survey of opinion obtained gives a clear guide either for immediate administrative action or post-war Government policy, but this report does give a picture of current practice and problems, and of spontaneous uncensored opinion, which must be taken into account if British industry is to play an intelligent and constructive part in the framework of international economic relations as agreed between the Allied Governments and particularly between Great Britain and the United States.

By Harold Whitehead and Staff, Ltd., 31 Palace Street London S.W. 1. Price 2s. 6d. net.

Metallography of Magnesium and its Alloys

For some considerable time there has existed a demand for a text book on the Metallography of Magnesium Alloys. Due to the expanded war-time applications of these materials, many metallurgists are dealing with magnesium alloys and require the routine type of metallographic data which is not contained in published papers. This recent publication, a translation from the German by the technical staffs of Messrs. F. A. Hughes and Messrs. Magnesium Elektron, has, in a large measure, fulfilled this need.

To the new-comer to the field of magnesium alloy metallography, this book will be of considerable assistance in solving his day-to-day problems, particularly as the book is profusely illustrated. To the metallurgist familiar with magnesium alloys, the book, although breaking no fresh ground, has neatly summarised his experience, thus providing a sound basis for future expansion. It might also be noted that the photomicrographs afford the reader considerable satisfaction, having obviously been carefully selected, and in the majority of cases, admirably reproduced.

It may appear unfortunate that the alloys considered are of German commercial types, but as these alloys correspond closely with British materials, the structures described and illustrated lose none of their value. A modification, which would certainly have been welcomed in the English version, would have been the introduction in Table I of a column containing the corresponding British specifications.

The authors have described at some length the characteristics of impurities in magnesium with the result that this chapter is particularly valuable. The metallography of the wrought manganese alloy and the wrought aluminium-zinc alloys are covered in some detail, particular attention being directed to the mechanism of recrystallisation and the effects of heat-treatment. It is unfortunate that the word "eutectoid" has been employed to describe the characteristic precipitation of the aluminium-bearing alloys. The transformation thus implied does not occur in aluminium-magnesium alloys, these structures being solely the product of precipitation from a solid solution.

The sections devoted to corrosion and welding are rather incomplete and could, with advantage, have been expanded by the translators. The occurrence of flux inclusions both in castings and welds may lead to serious corrosion and it would seem that some discussion of this feature would not have been out of place.

In the case of castings, particularly sand castings, no mention is made of the influence of superheating which exerts considerable influence on the microstructure and mechanical properties. Superheating is so important as an essential feature in the production of magnesium alloy castings that no reference to its effects seems to be a serious omission.

As explained in the preface, no equilibrium diagrams are reproduced but the more important might advantageously have been included.

By W. Bulian and E. Fahrenhorst; an English translation published by F. A. Hughes & Co. Ltd., Lumino Lane, Clifton Junction, Swinton, Manchester. Price 15s., postage 6d. extra.

Talks about Export

If a satisfactory volume of overseas trade is to be achieved after the war, there will be need for the highest degree of technical efficiency, not only in production, but also in distribution. Scientific research to ensure that British goods and the manufacturing processes which go to their production are technically efficient may be wholly valueless if market research has not previously established that overseas demand exists, that local requirements are considered, prejudices avoided, and a competitive price attained. Marketing abroad presents problems entirely different from those encountered in the home country. Many of these problems are discussed in this book, which contains the substance of 24 popular lectures delivered by three experienced and specialised lecturers at meetings organised by the Institute of Export during the spring of this year.

The subjects, which include shipping practice, the finance of export trade, and marine insurance, are not by any means fully covered, but interested readers will find sufficient to increase their desire to make a more comprehensive study of export problems. This useful book certainly shows how broad is the field in which proficiency in the export trade must be sought.

Published by the Institute of Export, Royal Empire Society Building, Northumberland Avenue, London, W.C. 2. Price 2s. 6d. net.

Temperature Control

It is gradually becoming recognised that the automatic control of temperature for space heating and for a wide variety of heating and cooling processes is essential for economy of plant operation. In many instances accurate temperature control is the final answer to the problem of meeting the intensified fuel situation. In order that available knowledge on the subject may become more widespread, the technical staff of Sarco Thermostats, Ltd., have prepared a series of papers which tell the story of temperature control for heating and industrial purposes. As the number of copies available is limited, interested readers are asked to apply without delay to Messrs. Sarco Thermostats, Ltd., Cheltenham, Glos.

Wellman-Mesta Collaboration

The Wellman Smith Owen Engineering Corporation, Ltd., have sought to re-establish their pre-war connection with Mesta Machine Co., of Homestead, Pa., and have now made arrangements for exclusive rights for the sale and installation of Mesta rolling mills, rolling mill appliances, hydraulic presses, etc., in Britain.

Free communication between the United States of America and Great Britain is still difficult, and some delay inevitable, but it is hoped that under post-war conditions a free interchange of information and personnel will give every facility for placing at the disposal the British industry the extensive engineering resources of these two companies for the design and manufacture of steelworks equipment of all kinds. Those wishing to consider plans for reconstruction or extension in this field are asked to communicate with the Wellman Smith Owen Engineering Corporation, Ltd., in good time.

MICROCHEMISTRY
APPARATUS · METALLURGICAL APPLICATIONS · TECHNIQUE

RECENTLY, in a contemporary, the writer of a letter complained, "From the point of view of the works' chemist, the limitations (of microchemistry) are twofold: (1) The need for a microbalance, which in most works involves special foundations, etc., to cut out vibration. . . . Leaving out the use of methods demanding special weighing appliances, there are semi-micro methods deserving the attention of the chemist, and demanding nothing more than a really good balance." The first of these statements is so commonly held that the article below needs no other justification. Arising from the many confusing and contradictory statements which have been published, Dr. Wilson's article is based partly on experience, and partly on extensive inquiries made from users and makers of microchemical balances in this country. As for the second point, that there is a time and a place for everything is a proverb which nowhere needs stressing more than in this connection. Leave out special weighing appliances by all means if there is no doubt that the methods of microchemistry have nothing to contribute to the particular problem under investigation. But—and this is one of the occasions when a writer wishes that it were an easy matter for a printer to compose in red type—please remember that there are problems to which microchemistry will supply an answer more readily: and there are other problems which, without microchemistry, will remain unsolved.

Problems Concerning the Microchemical Balance

Part I.—Installations

By Cecil L. Wilson, M.Sc., Ph.D., A.R.I.C.

A number of precautions must be taken when installing a microchemical balance. The more important of these are considered, and it is shown that in the majority of cases serious expense or extensive structural alterations are not to be anticipated.

THE advantages to be derived from the use of microchemical methods in general, and of the microchemical balance in particular, both in industrial and academic research problems, have been sufficiently stressed elsewhere,[1] and need not be further enlarged on here. Such methods are now widely used, and it is felt that it is only an exaggerated idea of the difficulties connected with the development of microchemical work which prevents them from being more generally adopted.

In particular, there seems to be a widespread belief among non-microchemists that the installation of a microchemical balance in the ordinary chemical laboratory will inevitably involve an expense which is too great to be borne by a small concern. It may be stated here that *if the circumstances are reasonably normal* this idea is without foundation.

In general, the type of microchemical balance used for ordinary analytical purposes is derived from the short-beam balance which Kuhlmann developed from his precision assay balance. This balance was first developed, under the direction of Emich, in 1910.[2] Although the Kuhlmann balance was by no means the first microchemical balance,[3] and although there are a number of other balances applying radically different principles,[4] it may be understood that it is to short-beam balances, either of the direct-reading type or the damped scale-reading type, that the remarks in this article apply specifically. It is reasonable, however, to assume that the remarks will have an application to most other types of balance as well.

In the installation and mounting of the balance, it may be reckoned that five major factors will have to be taken into consideration. These are vibration, temperature, humidity, dust and fumes. These points will be dealt with in turn.

Vibration

If a microchemical laboratory is being designed *ab initio*, then it is obviously desirable that some form of rigid table, preferably set on a pillar standing on the ground, independent of the building, should be

1 See *e.g.* Belcher, *Chem. and Ind.*, 1941, **605**; Strauss, *Chem. Products*, 1941, Nov.-Dec., 5; Wyatt, *Chem. and Ind.*, 1942, **132**.
2 Emich, *Lehrbuch der Mikrochemie*, 1926, p. 71.

3 The first microchemical balance in the true sense of the word was probably that by Warburg and Imori (*Ann. Phys. Chem.*, 1886, **27**, 481). For the history of the microchemical balance, see *e.g.* Kuck and Loewenstein, *J. Chem. Educ.*, 1940, **17**, 171.
It is not generally known that Joseph Black, about 1790, devised a balance for weighing small amounts, probably one of the first chemical balances to employ the principle of the rider. (*Ann. Phil., New Series*, 1825, **10**, 52).
4 See *e.g.* Kuck and Loewenstein, *loc. cit.* Gorbach, *Mik.*, 1936, **20**, 286.

provided. However, where the problem of installing a balance in an already existing building is to be met, it is rarely necessary that such a table must be built. Excessive vibration, it is true, may prove to be an almost insuperable difficulty; but where the amount of vibration is not more than one would normally expect—*e.g.*, arising from heavy traffic outside the building, or machinery in a remote part of the building, then it may usually be overcome by much simpler expedients. A solid bench, or a slate or concrete slab bolted to a solid wall, has in many cases been found to be adequately stable. As an extra precaution, the balance may be placed on several thicknesses of cork, linoleum or leather. An alternative which serves to deaden much vibration is a sheet of lead between sheets of plate glass. In any case, balance mountings which show any considerable amount of flexibility are to be avoided, as there is considerable risk of pushing the balance out of the vertical by such simple processes as raising the beam. This would, of course, give rise to serious errors in the use of the balance—probably more so than the vibration which was being overcome.

It is worth remembering in selecting a site for the balance table that it need not necessarily be on the ground floor. In fact, in modern buildings which are strongly constructed it may be an advantage, if a wall or bench mounting is preferred, to pick a site on an upper floor, as thereby street vibration will probably be much reduced.

Temperature

Variations in temperature may have a much more deleterious effect on the accuracy of microchemical weighing than even the most serious vibration. If it is at all possible, a room on the north side of the building should be chosen as the microchemical laboratory. Thus an initial advantage in the way of equable temperature, and the avoidance of direct sunlight on the balance, is achieved. The positioning of the balance will naturally have to be carried out with due regard to doors and windows, and to radiators. In other words, the balance should not be between two doors or windows which would give rise to draughts directly on to the balance. If the room contains a radiator, it is best that the balance should be placed *exactly* opposite to it. Even the position of lights must receive attention. Any light near the balance should be placed symmetrically with regard to the balance, otherwise the rest point of the balance will show a drift. This of course applies to the light designed to illuminate the balance case, which in addition should preferably be at least 6 ft. above the balance.

It must be stressed that temperature gradients may give rise to errors of as much as 100 micrograms, so that close attention must be given to these points.

Other Factors

Changes in humidity can have an appreciable, but not in general a serious, effect on microchemical weighings. It has been determined[5] that a change from 20 to 90% relative humidity altered the zero point of a Kuhlmann balance by 15 micrograms. Since a *change* of this order is only likely to occur in this country through a serious fluctuation in temperature, it is probable that by paying sufficient attention to temperature control the humidity will be sufficiently regulated for all ordinary purposes.

It is probably almost unnecessary to stress that dust and fumes should as far as possible be prevented from coming into contact with the microchemical balance. In view of this, and of humidity problems, it has often been suggested that a microchemical laboratory should be air-conditioned, but this is not, in the opinion of the author, essential. In industrial districts where the trouble is likely to be very serious, some advantage may be derived from a fan arranged so as to maintain a slight positive pressure of filtered air in the balance-room, but it is rarely that even this precaution will be found necessary.

I am much indebted to Messrs. L. Oertling, Ltd., and to the late Dr. H. J. S. Sand, for some of the information contained in this article.

5 Corwin, *Ind. Eng. Chem., Anal. Ed.*, 1944, **16**, 258.

Notes on Dropping Mercury Electrodes, I.

By J. T. Stock

FOR polarographic work, amperometric titrations, etc., a satisfactory dropping mercury electrode is essential. Generally speaking, a drop-time of about 3 secs. is desirable, although when the readings of a long-period galvanometer are recorded manually, a somewhat slower rate of dropping may be used. With the original type of electrode, made by drawing out hard glass tubing, the desired conditions are readily obtainable, owing to rapidity of fabrication. Though this type of electrode gives perfectly satisfactory results, it is of necessity somewhat fragile, and its breakage necessitates restandardisation. Accordingly, dropping electrodes made from stout capillary tubing of extremely fine bore are favoured.

With tubing of about 0·05 mm. bore, a piece of from 6 to 8 cm. long gives an approximately correct drop time. In most cases it is possible to use a tube of this length "as cut," the mercury reservoir being attached by flexible tubing. With tubing of finer bore, the required length is shorter, hence it becomes necessary to seal to a length of tubing of wider bore. This is also the case if an all-glass assembly is contemplated.*

Owing to the resistance offered by the fine capillary, it is not easy to blow out the end, a necessary preliminary to jointing.† It may be done as follows: Close one end by cautious heating in the blowpipe flame. Apply to the open end a pressure of about 10 lb. per sq. in., obtained via a reducing valve from a cylinder of non-inflammable gas (*e.g.*, oxygen). Heat the tip of the closed end, when a bubble appears, bursts, and may be chipped open. Using a small, hot flame directed away from the fine bore, seal the blown-out end to wide-bore tubing of slightly greater outside diameter. When cold,

* See, for example, "Aluminium: Spectrochemical and Polarographic Analysis," British Aluminium Co., Ltd., London, 1943, p. 64.

† G. J. Kahan, *Ind. Eng. Chem., Anal. Ed.*, 1942, **14**, 549. He also gives a method of blowing out the capillary which utilises the vapour pressure of mercury.

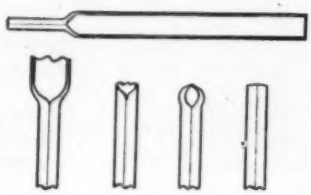


Fig. 1.—Stages in sealing on fine capillary.

immerse the tip of the capillary in a little pure mercury and apply water-pump suction to the upper end. A bead of mercury should appear above the seal within a minute or so. If not, examination under the microscope will probably show partial or complete obstruction. If the fine part is not too short, cut it off for a further attempt. By this method, capillaries of bore as small as 0·03 mm. may be used. A length of only about 1·5 cm. is required to give a 3 secs. drop time with a mercury head of 50 cm.

It is not easy to adjust the drop-time by breaking off short lengths of the stout capillary. Hence the approximate length is ascertained by a preliminary experiment, then a piece of capillary 1 cm. or so longer is cut and sealed on. With the desired head of mercury, the drop-time is determined. Since the latter is proportional to the length of uniform capillary, the correct length is readily calculated and the excess cut off in one piece.

A Micro-Burette with Adjustable Efflux

By J. T. Stock and M. A. Fill

ALTHOUGH lacking the precise control afforded by burettes of "syringe" or "micrometer" design,[1] the gravity-discharge type of micro-burette has always been popular owing to its comparative simplicity and ease of construction. The apparatus described below incorporates a built-in modification of the capillary brake method of control[2] of the gravity discharge and enables the rate of flow to be varied within wide limits.

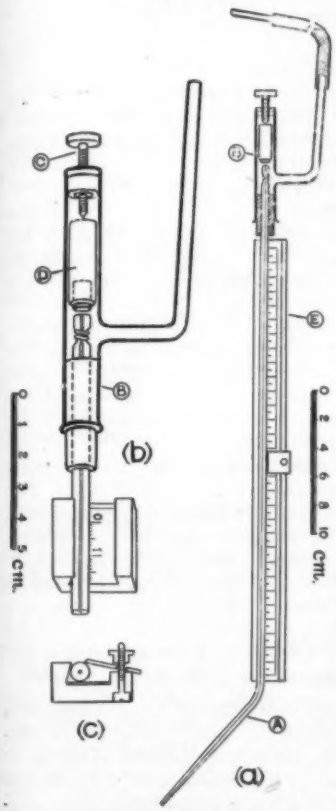


Fig. 1.—Constructional details of the micro-burette.

The general design of the apparatus is shown in Fig. 1 (*a*). The stem A is constructed from heavy-walled tubing of suitable bore, one end being drawn out and bent over to form a jet. The other end is constricted to limit the rate of flow to a desirable maximum. A simple way of doing this is to heat the tube until it softens and to rotate the projecting end through approximately two turns while holding the main part stationary. This "wringing" motion causes considerable local reduction of the bore without causing its complete collapse. When cold, the excess is cut off squarely a few millimetres beyond the constriction and the end ground slightly convex with the aid of carborundum paste. After removal of the latter, the finished stem is well cleaned with warm nitric acid.

By means of a snugly fitting sleeve of rubber tubing, the stem is attached to control housing B, which has a 2 BA nut or similar female threaded portion cemented in its outer end. Control screw C is a 2 BA or similar screw to which the knurled head of a terminal is soldered.

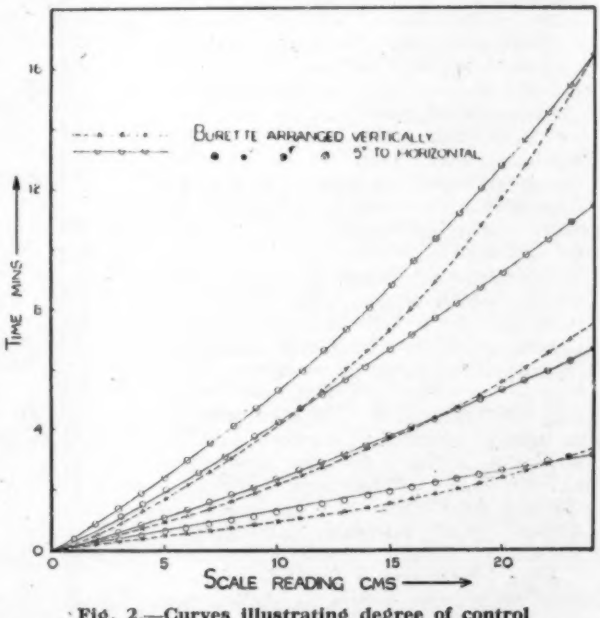


Fig. 2.—Curves illustrating degree of control obtainable.

Piston D is made from a short length of brass tube which is an easy fit within the housing. One end is closed with a drop of solder and filed flat, while the other carries a small plug of rubber cut with a cork borer. The plug is forced into position so that its projecting face is squarely presented to the ground end of the burette-stem.

1 For an extensive review of burettes and other micro-volumetric apparatus, see G. H. Wyatt, *Analyst*, 1944, **69**, 81.

2 A. Benedetti-Pichler. *Z. anal. Chem.*, 1928, **73**, 200.

With C slackened off and the jet dipping into the desired reagent, the burette is filled by applying gentle suction to the mouthpiece. Before releasing the suction, C is *lightly* screwed down, preventing further movement of the liquid column. Delivery of the reagent can be effectively controlled by subsequent operation of the screw, provided the latter is not over-tightened. Very light pressure arrests the flow.

It is not always easy to mount long, slender burettes so that they may be readily detached for cleaning. The scale unit E serves as a rigid, safe support, and enables the apparatus to be held in any position by means of an ordinary stand and clamp. The burette may be removed bodily by loosening the single thumbscrew, which frees the sheet-celluloid clip. A cross-section through the scale unit is shown at (*c*) in Fig. 1, indicating the mounting of the celluloid scale in the wooden framework, and also the action of the clip. The ease of attachment of both control and scale units permits the ready interchanging of one burette-stem for another of different capacity.

Efflux curves obtained using a burette-stem of 1 mm. bore are shown in Fig. 2. Used in the horizontal position, the rate of flow is almost constant. If the burette is filled between runs without altering the setting of the screw, the degree of reproducibility is quite good :—

Scale reading, cm.	4	..	8	..	12	..	16	..	20	.. 24
First run, secs.	29	..	59	..	90	..	124	..	159	.. 196
Second run, secs.	30	..	60	..	95	..	128	..	164	.. 203

The curves shown do not by any means indicate the slowest rates of flow which are obtainable. Owing to the small volume of air above the liquid column, temperature effects are not pronounced.

The burette-stems are calibrated by any of the usual methods, such as the measurement of the length of a mercury thread. After use, the burette should be emptied, rinsed, and allowed to drain with the tip in contact with a pad of filter paper. This prevents irregular action due to condensation in the construction.

A Simple Thermo-Regulator

By J. T. Stock and M. A. Fill

A SMALL water-bath, such as is used in micro-chemical operations, has the great advantage of rapidly attaining the desired working temperature. Owing to the small mass of water, however, it is not easy to maintain this temperature even within quite wide limits without almost constant attention. The usual toluene-mercury regulator of course permits accurate control, but is neither necessary nor convenient for this purpose. We have for some time been using a simple regulator, working on the principle of the air thermometer, which is easy to construct and is rapidly adjustable to maintain any desired temperature between 40° and 95° C.

The stem A is of stout glass, and has a bore of about 4 mm. Its lower end is sealed into a bulb of about 15 ml. capacity, as shown in Fig. 1 (*a*). The lubricated rubber sleeve B permits tee-piece C to be moved up and down the stem. Into the top of C the gas inlet tube D is tightly cemented; the lower end of the latter is drawn down to a bore of about 1·5 mm. A tiny hole is blown in the gas inlet tube at E, providing a by-pass which prevents extinction of the heating flame.

After introducing a few mls. of mercury, preliminary setting is carried out by cooling the bulb in ice-water. The stem is then held horizontally, and the residual beads of mercury are blown into the bulb. On allowing to return to normal temperature in the vertical position, mercury rises in the stem. The apparatus is then assembled and the bulb immersed in the water in the bath. The regulator is connected in the gas lead as usual. A semi-luminous burner arranged 10–15 cm. below the bottom of the bath gives even heating.

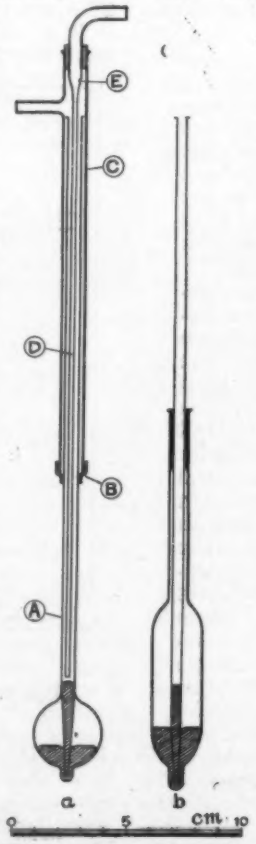


Fig. 1.—Thermo-regulator—alternative methods of construction.

Having attained the desired temperature, C is moved until the tip of D just makes contact with the mercury surface. Final adjustments are made a few minutes later. To assist initial setting, an index mark may be scratched near the upper end of A and a narrow paper scale attached to the inside of C.

Once adjusted, the regulator maintains the selected temperature within a degree, and since it can be so readily reset, has proved very useful for a variety of purposes, a 600 ml. squat beaker being used as a bath.

A modified form of construction, using a broken pipette, is shown at (*b*). The joint is made by a tightly-fitting sleeve of rubber tubing, surmounted by a layer of Chatterton's compound, and is so arranged as to be well above the surface of the water.

The Volumetric Determination of Aluminium in Magnesium Alloys.

AN alkalimetric titration method has been developed for the determination of aluminium in magnesium alloys.* The excess of free acid in a solution of the alloy is neutralised with sodium hydroxide solution, using a screened indicator, and the aluminium is then determined, using a second indicator, by titration of the equivalent amount of acid liberated by the addition of sodium citrate. The only interfering metal in normal "Elektron" alloys is manganese, but a simple correction can be applied.

* C. H. Wood. *Journal of the Soc. of Chemical Industry*, LXII, October, 1944, No. 10, pp. 317–320.

Tempering of Steel

AT the twenty-fifth Annual Convention of the American Society for Metals, three papers were presented dealing with the tempering of steel. The various aspects of the subject treated were the structural changes occurring during the tempering of high carbon steels, the effect of carbon content on the tempering characteristics of plain carbon steels and the tempering of nickel and nickel-molybdenum steels.

In the first paper,[1] D. P. Antia, S. G. Fletcher and M. Cohen, point out that, although the tempering of plain carbon steel is ordinarily regarded as a comparatively simple process, the prevailing theories of tempering are not consistent with the available data, and therefore an investigation was made with combined X-Ray, metallographic, hardness, magnetic, dilatometric and specific volume tests to clarify the many issues involved. The investigations were made on a commercial carbon steel, an iron-carbon alloy and a nickel steel suitably hardened, the compositions and hardening treatments of these materials being given in Table I. The tempering treatments were of the following type: (*a*) Continuous tempering consisting of heating to 540° C. at 2·8° C. per minute and cooling at the same rate for dilution and magnetic measurements. (*b*) Interrupted tempering consisting of heating to progressively higher temperatures usually at 28° C. intervals for 5-minute periods, with recurrent cooling to room temperature for X-ray diffraction, specific volume, metallographic and hardness measurements. (*c*) Isothermal tempering in which measurements of dilation and magnetisation were made at the temperature, while periodic cooling to room temperature permitted X-ray diffraction, specific volume, metallographic and hardness measurements. (*d*) Special tempering devised to follow the developments of cementite as revealed by its Curie points behaviour.

The results obtained from the various tests show that high-carbon steel, whether of high purity or of commercial grade, undergoes three pronounced stages during tempering. The first of these stages is caused by the decomposition of the tetragonal martensite into an aggregate consisting of ferrite and a transition precipitate. This precipitate is not cementite, but ultimately transforms in to cementite during the third stage of tempering. The second stage of tempering is characterised by the decomposition of the retained austenite into an acicular product having the same state of aggregation as the tempered martensite. The third stage is caused by the genesis and development of cementite from the transition precipitate formed during the first two stages. Agglomeration of the cementite particles takes place during, as well as after, the third stage until a typical spheroidised structure is attained. All the tempering reactions are time-dependent, occurring at lower temperatures, with longer tempering times and there is evidence of stress relief overlapping the three tempering stages.

The effects of carbon content on the tempering temperature were studied by means of similar measurements by Fletcher and Cohen[2] in an investigation confined to commercial carbon steels and high-purity iron-carbon alloys which were treated so that only tetragonal martensite and retained austenite existed in the structure prior to tempering. The composition, austenising temperatures, and amounts of retained austenite determined by specific vloume method, except in the case of the low-carbon steel where the austenite was estimated from X-ray diffraction data, are given in Table II, and show that the retained austenite increases rapidly with the carbon content and that high purity alloys retain less austenite than the corresponding steels.

All the steels tested show the three fundamental stages of tempering previously dealt with, but in a varying degree. Data obtained from the various tests indicate that carbon appears to have little effect on the temperature ranges over which these stages occur, and on the rates of reaction within each stage. The property changes, however, associated with each stage of tempering become intensified as the carbon content increases provided that account is taken of the amount of martensite or austenite participating in the transformation. The extensive hardness data obtained indicate that the first stage, tempering of the tetragonal martensite, is a hardening reaction,

TABLE II.
COMPOSITION AND AUSTENISING TREATMENT OF CARBON STEELS AND IRON-CARBON ALLOYS.

No.	Alloy.	Composition.						Austenising Treatment.	Retained Austenite, %.
		C.	Si.	Mn.	S.	P.	Ni.		
A	Carbon steel	0·49	0·10	0·53	0·036	0·063	0·12	815° C.—water	2
B	" "	0·94	0·13	0·33	0·015	0·009	Nil	815° C.—water	13
C	" "	1·02	0·19	0·35	0·007	0·019	trace	855° C.—oil	21
D	" "	1·26	0·17	0·34	0·023	0·014	0·16	980° C.—oil	35
4	Iron-carbon alloy	0·63	0·004	Nil	0·006	0·003	Nil	815° C.—water	2
23	" "	0·79	0·01	Nil	0·004	0·003	trace	815° C.—water	6
9	" "	0·95	0·004	Nil	0·006	0·003	Nil	815° C.—water	9

TABLE I.
COMPOSITION AND AUSTENISING TREATMENT OF CARBON AND ALLOY STEELS.

Material.	Composition.						Austenising Treatment.	Retained Austenite, %.
	C.	Si.	Mn.	S.	P.	Ni.		
Carbon steel	0·94	0·13	0·33	0·015	0·009	Nil	815° C.—30 mins.—water	13 (*a*)
Iron-carbon alloy ..	0·95	0·004	Nil	0·006	0·003	Nil	815° C.—30 mins.—water	9 (*a*)
Nickel steel	1·00	0·01	0·43	0·05	0·05	4·82	925° C.—30 mins.—oil	37(*a*) 48 (*b*)

(*a*) 0·24 round section. (*b*) 0·5 square section.

1 *Trans. Amer. Soc. for Metals*, 1944, vol. 32, pp. 290-324.

2 *Trans. Amer. Soc. for Metals*, 1944, vol. 32, pp. 333–357.

increasing in magnitude with increasing carbon content. While the decomposition of retained austenite, second stage, is also a hardening transformation, the secondary hardening produced becomes pronounced only when more than 20% austenite is initially present. The third stage, formation and growth of cementite, results in marked softening.

Calculations based on the dilatometric and lattice parameter tests demonstrate that cementite is not formed to any appreciable extent during the initial tempering of martensite, but that there are strong indications that a transition structure precipitates during this transformation. The volumetric effects of the second and third stages of tempering, which normally overlap, may also be separated by suitable calculations. These various calculations, however, confirm that increasing carbon content brings about intensification of the changes on tempering.

In the third paper by Anita and Cohen[3], the tempering of nickel and nickel-molybdenum steels is dealt with. The nickel steels used in the investigation contain 0·4 to 1·0% carbon, and 3·6 to 4·8% nickel and the two nickel-molybdenum steels 0·75% carbon, 3·58% nickel with 0·24 and 0·47% of molybdenum respectively. After oil-quenching from 925° C. it was found that carbon and nickel both tended to promote the retention of of austenite in hardened steel, the influence of carbon being much more effective than nickel. Molybdenum up to 0·5% caused a slight decrease in the amount of retained austenite from 14 to 12%.

X-ray, dilation, magnetic and hardness tests show that nickel and nickel-molybdenum steels pass through the same three stages of tempering as do the plain carbon steels. Nickel is found to have a definite, but relatively slight, stabilising influence on the retained austenite during tempering, while carbon up to 1·0 and molybdenum up to 0·5% have every effect on the stability. The retained austenite in these alloy steels is also found to decompose either isothermally or on heating to the tempering temperatures, and there is no evidence of austenite decomposition on cooling from the tempering temperature, such as occurs in high-speed steel. This difference in behaviour appears to be primarily of austenite stability, as it has been found that in high-carbon high-chromium steels, the retained austenite may be made to transform either on heating to, or on holding at, or on cooling from the tempering temperature depending on the extent of alloy-carbide solution achieved during the austenising treatment.

3 *Trans. Amer. Soc. for Metals*, 1944, vol. 32, pp. 363–378.

The Technical Cohesive Strength and Other Mechanical Properties of Metals at Low Temperatures

By D. J. McAdam and R. W. Mebs

IT has been shown that the technical cohesive strength of a metal in any particular state as regards prior mechanical treatment and heat-treatment, cannot be represented by a single value of algebraically greatest principal stress. The technical cohesive strength of any metal comprises an infinite number of technical cohesion limits, each corresponding to a specific combination of the principal stresses. The technical cohesive strength of a metal, therefore, must be represented by a diagram consisting of curves of variation of the cohesion limit with variation of the stress system.

In a previous investigation[1] the technical cohesive strength of metals at room temperature was studied and in the present investigation the experiments were extended to include an additional variable, temperature. Diagrams representing the technical cohesive strength of some metals at selected low temperatures are compared with corresponding diagrams representing the technical cohesive strength at room temperature. A study was also made of the quantitative variation of the technical cohesive strength, ultimate stress, yield stress and ductility throughout the range of temperature from that of liquid air (−188° C.) to +165° C. Diagrams of several types were used to show this variation and all the diagrams are based on the results of tensile tests of notched and unnotched specimens.

The alloys experimented with in the first part of the investigation included oxygen-free copper, Monel-metal, 13% chromium, 2% nickel steel, low-carbon steel and ingot iron (open-hearth-iron). In the second part of the investigation the same materials were used and additional materials introduced viz., nickel, aluminium, a copper-tin alloy and a 3½% nickel steel. In Table 1 are given the composition and treatments of the various materials experimented with.

From *American Society for Testing Metals*, 1943, Preprint 40, pp. 43.

1 METALLURGIA, 1944, vol. 30, pp. 59–60.

The method of investigation of the technical cohesive strength was based on the fact that when a notched cylindrical specimen is subjected to longitudinal tension, the minimum cross section is under transverse radial tension. The mean radial strength tends to increase with the depth and sharpness of the notch, but is always less than the longitudinal stress. The algebraically greatest principal stress (S_1) therefore is longitudinal and the radial stress is equivalent to the two equal stresses (S_2 and S_3), which are rotatable without change around the axis of the specimen. By the use of notched specimens it is possible to investigate the influence of the radial stress ratio (S_3/S_1) on the technical cohesion limit, ultimate stress, yield stress and ductility. In the low-temperature tests only deep notched test specimens were used.

Comparison of the diagrams representing technical cohesive strength, ultimate strength and yield strength for copper and Monel metal at 30° C. and −180° C. show that lowering the temperature from 30° to −180° C. has no effect on the qualitative forms of the curves, but has elevated the diagrams and increased the separation between the curves of ultimate stress and fracture. Although the amount of plastic deformation at fracture of copper and Monel metal differs little at the two temperatures, the strengthening effect of the deformation is much greater at −188° C. than at room temperature. The technical cohesive strength of the ferritic steels was investigated at 30° C., −78° C., −128°C. and −188° C. and somewhat similar results were obtained. Because of the decrease in ductility of these steels as the temperature is lowered, only incomplete diagrams of cohesive strength were obtained at −128° and −188° C. With the 13% chromium, 2% nickel steel at −128° C. the ductility was sufficient to permit the load to reach a true maximum when the notch angle

TABLE I.—COMPOSITION, MECHANICAL TREATMENT AND HEAT TREATMENT OF THE VARIOUS METALS AND ALLOYS.

Material	Mechanical Treatment	Heat-Treatment	Composition.										
			C	F	Ni	Cu	Cr	Al	Sn	Mn	P	S	Si
Oxygen Free Copper ..	Cold-Rolled	425° C. for 5 hours. Cool in air ..	—	—	—	99·97	—	—	—	—	—	—	—
Monel Metal	Cold-Drawn	750° C. for 1 hour Cool in water ..	0·18	1·24	Dif.	28·46	—	—	—	0·94	—	0·007	0·10
Nickel	"	———	0·07	0·08	99·49	0·03	—	—	—	0·24	—	0·005	0·08
Pure Aluminium	"	———	—	—	—	—	—	99·97	—	—	—	—	—
Commercial Aluminium..	"	———	—	—	—	—	—	99·4	—	—	—	—	—
Copper-Tin Alloy	"	———	—	0·01	—	Dif.	—	—	3·9	—	0·3	—	—
Ingot Iron	"	955° C. for 1 hour Cool in furnace ..	0·015	Dif.	—	—	—	—	—	0·05	0·003	0·025	0·01
0·04% Carbon Steel ..	"	955° C. for 1 hour Cool in furnace ..	0·045	Dif.	—	—	—	—	—	0·04	0·003	0·03	0·01
0·20% Carbon Steel ..	Hot-Rolled	885° C. for 1 hour Cool in water, 475° C. for 2 hours Cool in air ..	0·2	Dif.	—	—	—	—	—	0·42	0·039	0·049	0·21
3·5% Nickel Steel	"	800° C. for ½ hour Cool in Oil. .. 540° C. for 1 hour Cool in air	0·34	Dif.	3·30	—	—	—	—	0·72	0·018	0·017	0·26
13% Cr, 2% Ni Steel ..	"	———	0·09	Dif.	2·06	—	13·3	—	—	0·48	—	—	0·26

was 90° or more, but at −188° C. fracture was definitely premature when the notch angle was 120°. With the ingot iron at −128° C. the load barely reached a true maximum when the notch angle was 150° and at −188° C. the ductility was barely enough to permit the determination of the ultimate stress with an unnotched specimen, and even at −78° C. fracture was premature when the notch angles were 58 and 30°.

Variations of technical cohesive strength and other properties with temperature were also studied not only with reference to the usual arithmetical scale of temperatures, but also with reference to a temperature scale of equal thermo-dynamic efficiencies. From curves showing the effect of temperature on the yield, maximum and "true breaking" stress, a strictly linear relationship, for all the metals and alloys in Table I, is found to exist between strength and temperature expressed on the latter scale (i.e. the log of the temperature in °K) and to hold for both notched and unnotched specimens. There is also no indication that linearity ceases below −188°C.

Megacycle Induction Heating for Thin Cases

By V. M. Sherman

THE fundamental requirement of induction heat is the use of an alternating current and therefore induction heating can be accomplished with any frequency from the commercial 60 cycles up to millions of cycles per second. Most recent of all developments in the induction heating field is the use of frequencies higher than 1,000,000 cycles (1 megacycle) per second for metal treatment. Such ultra-high frequencies, produced with the vacuum tube unit, are particularly useful for the production of very thin cases using the mass of cold underlying metal as the quenching medium rather than externally applied water. With the energy concentrated into a thin surface layer, and with the energy developed in as little as 1 second or less, there is no time for an appreciable amount of the surface heat to be conducted into the core. The depth of the hardened case, if controlled by the condition of heating and not by the condition of cooling and case depth, is therefore independent of the shape of the part and may be made as thin as $\frac{3}{1000}$ in. or as deep as $\frac{60}{1000}$ in..

Megacycle energy has a number of practical advantages over slow-speed low-frequency induction heating in addition to its ability to confine its heat to the surface layer. When the heat-treatment is accomplished in one second or less, oxidation or scaling is completely eliminated even in ordinary atmosphere. A tempering or weakening of an internal layer due to excessive stored heat in a too thick surface layer is encountered with low-frequency heating and is directly traceable to the long heating time which allows the heat to penetrate too deeply into the core. This disadvantage is eliminated with megacycle heat for periods of 1 second or less. Distortion or warping is closely associated with uniform case thickness, and the amount of distortion experienced with megacycle heat has in all cases been negligible owing to

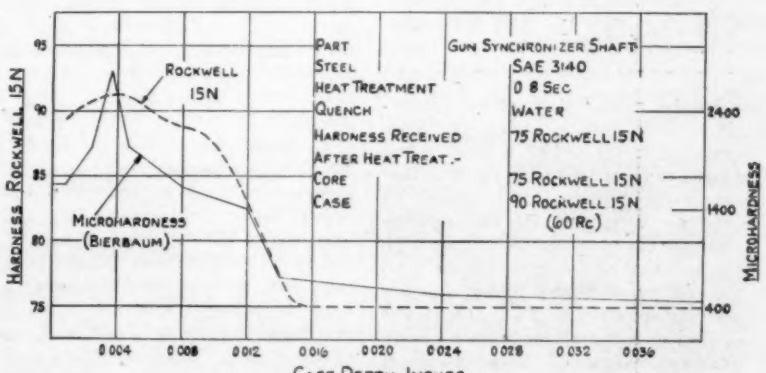


Fig. 1.—Hardness gradient from surface to core of gun synchroniser shaft.

From *Metals and Alloys*, 1944, vol. 19, No. 6, pp. 1409-1414.

the uniform section of the case resulting in a uniform stress which is small because the hardened layer is thin. Small parts and thin walled parts can be satisfactorily treated, but it is essential that a frequency in the order of 2 million to 15 million cycles per second be used. The use of smaller heating coils and less critical spacing between coils and the part treated is another and highly practical consequence of megacycle induction heating.

An illustration of how megacycle induction heating hardens the surface without softening the core is given in Fig. 1, which shows the variation in hardness of the case as measured from the outside into the core material of a gun synchroniser shaft. Neither the superficial Rockwell results nor the Bierbaum micro-hardness curve fall below 75 Rockwell 15N, the original hardness of the core material. Other successful applications of megacycle heating are in the hardening of spur gears, engine rocker arms, wing hinge bolts and Navy sextant gear.

Producing Copper-Zinc-Silicon Bronze Castings

By R. J. Keeley

COPPER-BASE alloys of the yellow or high brass type containing, silicon have been in use for many years although the silicon-containing alloys with higher copper and lower zinc content have been scientifically investigated only within the last decade. It was found that a valuable series of workable, corrosion resistant alloys can be produced with silicon ranging from 0.5 to 6.0%, with from 1 to 19% zinc and the remainder copper. Three grades of copper-zinc-silicon alloys are in wide usage and these are given in Table I together with their approximate mechanical properties. The values obtained for the physical properties of these alloys show them to be much superior to standard copper-tin bronzes.

TABLE I.

COMPOSITION OF STRENGTH OF SILICON BRONZES.

No.	Composition				Ult. Stress Tons per sq.in.	Elong. 2 in.	Brinell Hardness.
	Cu	Zn	Si	Pb			
1	R	13·7	4·8	—	30·0	20	140
2	R	5·0	5·0	—	25·0	40	110
3	R	5·5	3·8	0·75	30·0	30	120

In the manufacture of all copper-zinc-silicon bronze alloys a more exacting metallurgical control is required as compared with the standard copper-tin bronzes, due largely to extreme variations in the melting points of the components, coupled with the fact that the element silicon is all too readily oxidisable under ordinary alloying conditions. To deal with the subject of manufacture from a wholly practical point of view, founders regularly producing castings from these alloys were invited to make representative castings using a pattern which was in regular use for the production of red brass or bronze castings which had to withstand some pressure, with the object of determining how silicon bronze would behave when handled under the same conditions as those standard alloys.

Castings for hose couplings produced from silicon bronze containing 5% silicon, 5% zinc, according to standard practice, showed leaks when subjected to a 90 lb. hydraulic pressure test when the runners and gates were in the drag. When the gating system was changed and gates were placed in the cope as well as in the drag, the castings withstood satisfactory pressure tests. Faucet and castings for oil piping equipment also showed leaks under similar hydraulic tests with runners and gates in the cope. As a change in gating could not be made owing to production difficulties, failures were eliminated by attaching a riser to the heaviest section of the casting. Castings for parts of automatic sprinkler equipment to withstand pressures up to 300 lb. were also produced in silicon bronzes Nos. 1 and 2, when properly gated.

To investigate surface defects in a No. 1 silicon bronze casting, experiments were made to reproduce such defects deliberately so as to determine their cause. Castings were poured at different temperatures, some heats were run to determine the effect of hard ramming and other heats to determine the effects of wet sand. All of them failed. Superheating the metal to 1,370° C., cooling to the normal pouring temperature of 1,040° C. and sandblasting the casting, however, revealed the defects and pointed to oxidised metal as being the cause of failure.

Tests were also carried out on silicon bronze alloy No. 2 cast in two Webbert test bars, similarly gated, and two wedge test bars, top and bottom gated, together with an ingot. The first four were cast in green sand and the ingot was chill cast. The physical tests obtained from these various test bars are given in Table II.

TABLE II.

TEST BARS OF SILICON BRONZE.

Test Bar	Casting Tem Deg. C.	Yield Point Tons per sq. in.	Ult. Stress Tons per sq. in.	Elong. 2 in.
Webbert ..	1070	9·9	25·9	36·5
Wedge Block..	1065	8·9	24·5	29·0
Ingot	1060	10·0	28·0	34·0
Webbert ..	1055	9·9	26·1	32·5
Wedge Block	1050	9·4	24·4	29·0

In general, the various investigations and tests show that the factors of importance in handling of silicon bronze include the elements of shrinkage, control of melting and pouring temperatures, proper gating and risering and avoidance of contamination with other alloys.

From *The Foundry*, 1944, vol. 72, No. 4, pp. 120–121, 260, 262, 266; No. 5, pp. 82–84, 162, 164.

Iron Ore Briquetting Process Patented

PATENTS covering a process of briquetting soft iron ores, concentrates, flue dust, or similar material, to produce a dense compact suitable for open-hearth or blast-furnace charging has recently been issued. This process comprises drying the ore material and subjecting it to briquetting pressures sufficient to compress and compact it and increasing the strength of the resulting briquets by heating them until they are case-hardened or incipiently sintered. An alternate process presses the fine dried ore into containers for furnace charging. Experimental briquets have been produced which can be substituted for high-grade lump ore suitable for use as an oxidizing agent in the open-hearth furnace or for open-hearth charging. Those made from several different Mesabi Range ores withstand rough handling—and have a specfic gravity of four plus. They may also make a premium blast furnace charge. Compared with loose Mesabi ores, they permit a freer circulation of the blast through the charge; dust losses which affect blast furnace capacity and

From *Engineering and Mining Journal*, May, 1944.

efficiency are cut down ; and the dense nature of the briquets permits delivery of a greater quantity of iron units to the hearth, thereby increasing production. Furthermore, dehydrated briquets require no drying in the blast-furnace, whereas the moist Lake Superior ores require and use extra heat from within the furnace for this purpose.

The briquets described appear complementary to, rather than competitive with, sinter. The percentage of sinter in a blast furnace is usually limited by its porosity. In the open-hearth, sinter, unless weighted with scrap, is too light. Also, as an oxidising agent, it does not have the desired oxygen content and usually contains unwanted carbon. Finest ore sizes are best suited for briquetting. A large part of the Mesabi ores, as mined, will pass through 100-mesh screens. Concentrates finer than 100-mesh, such as from washing plant tailings dumps, should make ideal briquetting material.

Preferred Orientation in Annealed 70-30 Brass Wire

By H. L. Burghoff and J. S. Porter

THE results are given of an investigation of the effect of cold-working and annealing treatments upon the occurrence of preferred orientation in annealed brass wire. All the wire used was processed from one portion as cut for extension from a cast billet containing 70·13% copper, 29·83% zinc, 0·01% lead, 0·01% iron, and 0·02% nickel. The billet section 8 in. in diameter, was extruded hot to ¾ in. diameter, after which it was processed by alternate cold-drawing and annealing treatment. The first annealings in processing were at about 600° C., and the next to the last reductions by drawing were 58%. The diameter of the finally annealed wire was 0·132 in. Semi-final annealings were carried out at 425°, 510° and 600° C. and reductions of 47·5, 74, 83·5 and 89·5% were employed in drawing to 0·132 in. The final annealings were at 465°, 565° and 675° C. The three semi-final annealings, the four final draws and the three final annealings yielded 36 differently processed materials of 0·132 in. in the annealed condition.

The microstructure of transverse and axial sections were examined and grain sizes were estimated for the semi-final and final annealings. The angles of the twin bands with respect to the wire axis were determined from photomicrographs of axial sections for several materials finally annealed at 565° and 675° C. and frequency distribution graphs of these were made, twins being counted on an area not symmetrically disposed with respect to the wire axis. Only one angular valve was taken to represent a group of parallel twin bands within one grain. The procedure could not be satisfactorily applied to the material annealed at 465° C., because the detail of many of the grains in the microstructure was not sufficiently clear for convenient handling.

From the data obtained it was found that the preferred orientation which may be designated most simply by the fibre axis [111], decreased in intensity as the semi-final annealing temperature increases, but increases in intensity as the severity of the final reduction by drawing increases and also as the final annealing temperature increases. The converse of each of the factors as stated is to be inferred and it is to be noted that the last two factors, final draw and final annealing, are the most important in determining the degree of preferredness.

The preferred orientation is accompanied by significant increases in yield strength, tensile strength and modulus of elasticity over the values obtained in randomly oriented wire of similar grain size. The annealings at 425°, 500° and 600° C. resulted in grain-sizes ranges of 0·010 to 0·012 mm., 0·030 to 0·35 mm., and 0·060 to 0·070 mm., respectively, and corresponding tensile strength ranges of 24·5 to 25·7, 22·8 to 23·2 and 21·4 to 22·3 tons per sq. in. respectively. Yield strengths of the wires drawn to final size with the heaviest reductions, particularly 83·5 and 89·5%, are materially higher than for the wire for which a 47·5% reduction was used in the final draw. Tensile strength and tensile strength grain-size curves for previous reductions of 74, 83·5 and 89·5% are displaced upwards to strength values about 15 to 20% higher than for wire drawn 47·5% before the final annealing. From the results obtained it is apparent that yield strength and tensile strength relationships with respect to grain-size parallel the occurrence of the preferred orientation and that the strength increases as the intensity of the preferred orientation increases.

In Table I are given the tensile properties of some 70–30 brass wire drawn 10% and mechanically straightened, and selected to represent the extreme processing conditions of the investigation, so that the most nearly random and the most strongly preferred orientations are represented.

From Metals Technology, 1944, Vol. 11, No. 3, A.I.M.M.E. Technical Publication No. 1688, 11 pages.

TABLE I.

TENSILE PROPERTIES OF 70-30 BRASS WIRE AS DRAWN 10% FROM 0·132 TO 0·125 ins. AND MECHANICALLY STRAIGHTENED.

Schedule to 0·132 in.			Modulus of Elasticity	Stress at 0·5% Extension	Tensile Strength	Elongation on 2 in.
Semi-final Anneal °C.	Reduction %	Final Anneal °C.	Lbs. per sq. in.	Tons per sq. in.	Tons per sq. in.	%
595	47·5	465	17,000,000	21·4	27·0	30
595	47·5	565	18,000,000	19·0	25·0	36
595	47·5	675	19,000,000	17·6	23·8	38
425	89·5	465	20,000,000	24·3	31·0	22
425	89·5	565	22,500,000	24·1	30·3	25
425	89·5	675	23,000,000	22·1	27·2	32

Copper Smelting in 1943

By E. A. Peretti.

THE American Smelting and Refining Company was able to increase the copper-lead ratio of both speiss and matte in handling copper in lead plants by a soda ash treatment in smelting the lead drosses. This eliminates the formation of all slags and is well suited for lead plants, where little speiss is formed and the copper content of the charge is high. The increase in the grade of copper concentrates has made direct smelting more attractive.

At Hudson Bay's Flin Flon plant the tonnage of pay charge treated and the amount of copper produced will be higher than for any previous year. Besides handling all available tonnage of concentrates through the roasters and reverberatory furnace, selected high-grade ore from the mine was smelted direct in the converters. A tunnel was blasted out alongside the

From *Engineering and Mining Journal*, February, 1944.

furnace and a track installed, so that a ladle could be run close to the tap-holes for tapping the matte. By installing suitable hoods and a 38,000 c.f.m.[3](1,075 m/min.) ventilating fan, matte-tapping has been made gas-free.

To conserve heat in the roaster gases for efficient operation of the Cottrell plant and to lessen the chance for corrosion, the new steel roaster flue has been fitted with about 1 in. (25 mm.) of plastic insulation. A screw conveyer has been installed under the flue to remove the dust to a hopper from which it is hauled to the furnace in cars.

Data was gathered and made public on how to recover copper from clad-steel scrap, the methods being: Direct melting, molten lead-bath treatment, electrochemical processes, scaling, sulphide scaling, ammonium sulphate leaching, and cupric ammonium carbonate leaching. An important contribution was that of F. W. Willard for the recovery of copper from copper-base scrap, with techniques differing, depending on the percentage of contained copper, ranging downward from 99 to 5% Cu.

Silicon Range in Plain and Chromium Cast Irons at Elevated Temperatures

By C. O. Burgess and R. W. Bishop

AN investigation undertaken to determine the effect of silicon content on the heat resistance of both plain and chromium cast irons. The cast irons selected for the investigation had carbon contents between 2·9 and 3·5%. The silicon range was deliberately limited to 2·5 to 7·0% in that the purpose of the tests was to determine whether an optimum silicon range existed above the maximum 2·5% silicon level usually employed by foundrymen and below the silicon level that might be expected to produce excessive brittleness or sensitivity to thermal shock. In addition to plain irons, a series of irons of similar silicon contents but containing 2% chromium were included in view of earlier work which had shown that such irons possessed unusual heat resistance.

From *Trans. Amer. Soc. for Metals.* 1944, vol. 33, pp. 455–476.

In a typical heating cycle for oxidation and growth tests, test specimens, 6 in. long cut from 1·2 in. diameter standard test bars, were inserted in a furnace brought to the test temperature. One hour was allowed for specimens to reach 800° C. and they were held at this temperature for 15 hours, then removed from the furnace and cooled in still air to room temperature. This procedure was repeated 34 times, until a total exposure of 500 hours at 800° C. was attained. Specimens from all the irons were heated simultaneously. The results obtained for growth and oxidation are shown in Figs. 1 and 2. Internal oxidation was also determined by estimating the oxygen content in two layers, an outer and an intermediate layer, and at the core of the growth test bars.

The tensile strength and Brinell hardness of the various irons was determined before and after prolonged exposure (500 hours) at 800° C. The plain cast irons showed a decided drop in strength at silicon levels below the 3·3 to 4·3% silicon range. Within this range, the strength remained approximately constant, and when it was exceeded, as at the 5·92% silicon level, the strength again showed a decrease. The 2% chromium irons showed an increase in strength at all silicon levels up to 4·72%. In the plain irons a decided drop in hardness was evident up to 3·5% silicon. Between 3·5 and 4·3% silicon the hardness remained approximately constant, but at 5·92% silicon the hardness after exposure was actually higher than in the as-cast condition due probably to strain set up by internal oxidation of the graphite flakes. A somewhat similar condition existed in the case of the 2% chromium irons except that the hardness after exposure was below the as-cast value until the silicon reached 6·32%, where an inversion again occurred.

The experiments showed that an optimum silicon range exists in which both plain and 2% chromium irons exhibit maximum resistance to growth, internal oxidation and general deterioration of their physical properties. This range lies between 3·5 and 4·5% silicon in the case of plain irons and between 3·0 and 4·0% silicon in the case of 2% chromium irons. If the silicon content exceeds this range to any considerable extent, both plain and chromium irons become subject

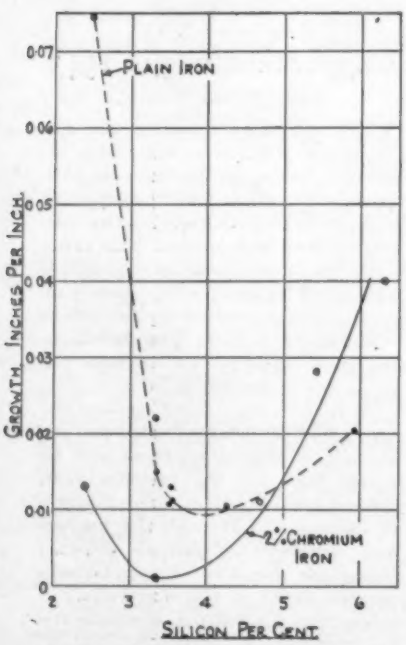


Fig. 1.—Growth versus silicon content after 500 hours at 800° C.

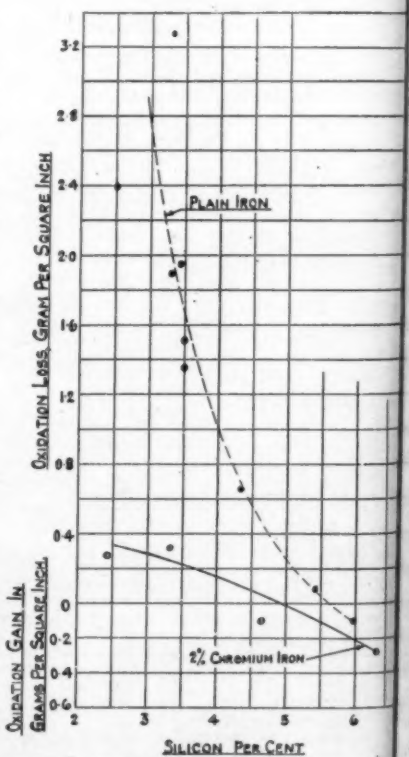


Fig. 2.—Oxidation loss or gain versus silicon content after 500 hours at 800° C.

to serious internal oxidation which proceeds along the graphite flakes and is sufficient to reduce the carbon contents of these irons to a negligible value. Plain irons in the optimum silicon range develop low tensile strengths in the as-cast condition, 6·7 to 8·9 tons per sq. in., and can only be used in sections in which oxidation resistance alone is of primary consideration. The 2% chromium irons maintain a high strength in excess of 16 tons per sq. in., throughout the optimum silicon range. These irons are also machinable and possess a desirable combination of properties that make them suitable for use in high temperature operations.

An Emergency Heat-Resistant Alloy

By O. E. Harder and J. T. Gow.

IN an attempt to develop heat-resistant alloys, low in scarce metals, for service up to 760° C., nearly 100 alloy compositions have been studied. The work done has included melting, casting, bend tests and tensile tests at room temperature, tensile and creep tests up to 870° C. and determination of the resistance of alloys to scaling in air and sulphur-bearing gases at temperatures of 760° and 870° C.

The most promising results were found with an alloy containing 0·30 to 0·35% carbon, 10 to 12% chromium, about 2% silicon, 4 to 10% manganese and 2 to 12% nickel, with the manganese and nickel supplementing each other and used in amounts to give a wholly austenitic alloy. Balancing the amount of manganese and nickel against the chromium content appeared to be the most important requirement for wholly austenitic alloys and it was significant that the amount of manganese and/or nickel required for such a structure increased as the chromium content decreased in the range 15 to 10%. Most of the work was done on alloys containing a maximum of 12% chromium, but it was also found that the corrosion resistance was improved by increasing the chromium content from 12 to 15%. Carbon within the range 0·30 to 0·35% seemed to have little effect whether or not the alloys were wholly austenitic, but as the carbon content increased over this range, the ductility of the alloys decreased. A preferred silicon content appeared to be 2% because the corrosion resistance was materially improved by increasing the silicon content from 1 to 2%, while, if the silicon content was increased from 2 to 3%, there was some loss in ductility. The nitrogen content ranged from 0·04 to 0·08% and no important effect was found to be associated with this variation in nitrogen content.

The most extensively studied alloy contained 0·35% carbon, 12·3% chromium, 2·28% silicon, 7·8% manganese and 7·8% nickel, was entirely austenitic in structure and was considered to have adequate strength, ductility, load carrying capacity as determined by creep tests, and resistance to oxidisation at 760° C. It also had adequate toughness for handling in the foundry, was low enough in hardness to be machinable, and did not develop excessive hardness or show marked loss in ductility or ageing at 760° C. The coefficient of thermal expansion of this alloy was slightly greater and its density slightly lower than that of alloys containing 25% chromium, 12% nickel. It was superior in all respects to 6% chromium steels and although 18–8 chromium-nickel steels were equal to it in many respects and superior in others, they required a substantially greater amount of scarce alloying metals.

From *Trans. Amer. Soc. for Metals*, 1944, vol. 32, pp. 408–475.

Physical Properties of A Copper-Manganese-Zinc Alloy

By J. R. Long and T. R. Graham

A REPORT concerned with part of a series of investigations carried out by the Federal Bureau of Mines on alloys, particularly non-ferrous alloys, made with electrolytic manganese. These investigations were instituted after commercial quantities of electrolytic manganese containing 0·01% iron, 0·02% sulphur and no silicon or aluminium became available, in order to compare the effects of electrolytic manganese with those of ordinary commercial grades containing up to 2% iron, a maximum of 1% silicon and 0·06% carbon. Experiments were restricted to comparison of the properties of 70–30 brass with those of a 65–10–25 copper-manganese-zinc alloy, prepared with ordinary commercial manganese as well as with electrolytic manganese.

TABLE I.—COMPOSITION OF ALLOYS.

Alloy	Cu	Zn	Mn	Fe	Si	Al
Cartridge Brass ..	68·25	31·70	Nil	Nil	Nil	Nil
Electrolytic Manganese	65·00	24·90	10·05	Nil	Nil	Nil
Ordinary Manganese	65·00	24·45	10·30	0·27	Nil	Nil

The alloys were made from high grade copper, electrolytic zinc, and two grades of manganese, high-purity electrolytic cathode chips and ordinary commercial metal. While melting and alloying, which consisted in adding a manganese-zinc hardener to molten copper, were mostly carried out in high-frequency induction furnaces, no difficulties were encountered in making the alloys in clay-graphite crucibles in a gas-fired furnace. All the alloys were chill cast into $1\frac{1}{2} \times 3 \times 19$ in. slabs which subsequently were machined to remove incidental surface imperfections. These slabs were hot-rolled (700° C.) and cold-rolled and annealed (530° C.) to produce sheet finished to $1\frac{1}{16}$ in. thickness by various amounts of cold-reduction. The composition of the alloys tested are given in Table I.

Tests were carried out on the copper-manganese-zinc alloy to determine the hot-working and cold-working characteristics; variation of physical proper-

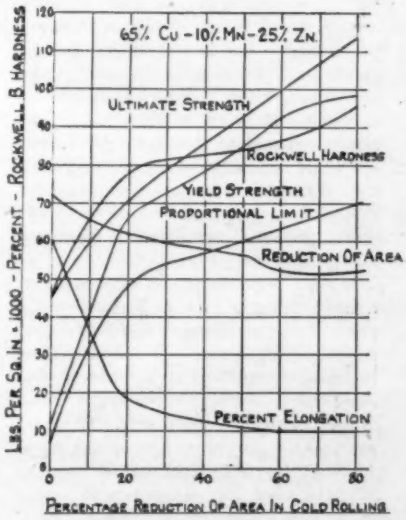

65% Cu - 10% Mn - 25% Zn.
Ultimate Strength
Rockwell Hardness
Yield Strength
Proportional Limit
Reduction Of Area
Percent Elongation
Lbs. Per Sq. In. × 1000 - Percent - Rockwell B Hardness
Percentage Reduction Of Area In Cold Rolling

Fig. 1.—Tensile properties of manganese alloy.

From *Metals Technology*. 1944, vol. 11, No. 4, A.I.M.M.E. Technical Publication No. 1705, 16 pages.

ties with cold-working and subsequent annealing; the effect of small variations in composition; microstructure and grain sizes, resistance to salt spray corrosion; susceptibility to season cracking; and the effect of lead and antimony additions on hot-rolling characteristics. In Fig. 1 are given the mechanical properties of the alloy.

In general, the physical properties of the alloy containing 65% copper, 10% manganese, 25% zinc, made with electrolytic manganese are intermediate between those of the alloy made with ordinary manganese and the properties of 70–30 brass. Upon exposure for 30 days in a salt spray chamber the electrolytic manganese alloy suffers the least loss in percentage elongation. The rate of grain growth of the electrolytic manganese alloy is less than that of brass and its grain size is slightly more than half of that for brass annealed at the same temperatures, while the ordinary manganese alloy shows an extremely fine grain size which is attributed to iron introduced with the manganese. Variations of 2·5% from the normal composition of the electrolytic manganese alloy show definite but not extreme changes in physical properties. The tolerances of the alloy for lead in hot-rolling is greater than that of brass and if 0·14% of lead is present the alloy may be successfully hot-rolled at 815° C. compared with a limit of 0·02% lead for 70–30 brass at 790° C. Lead and antimony together are more injurious to the hot-rolling characteristics of 70–30 brass than to those of the manganese alloy which can be readily rolled at 816° C. when containing as much as 0·1% lead and 0·01% antimony. Similar to 70–30 brass a 65–10–25 copper-manganese-zinc alloy is subject to season cracking but not to any greater extent.

The alpha boundary regions in this region of the copper-manganese-zinc system has also been established. Isotherms of the boundary almost parallel the constant copper-concentration lines of the diagram and move towards the copper corner with increasing temperature.

A 65–10–35 copper-manganese-zinc alloy may be processed into a rim-fired cartridge case without intermediate annealing, using punches and dies normally employed for brass.

Influence of Hydrogen on the Mechanical Properties of Some Low-Carbon Manganese-Iron Alloys and on Hadfield Manganese Steel

By H. H. Uhlig

THE mechanical properties of high-carbon manganese-iron alloys, particularly the Hadfield manganese steels have been established but discrepancies exist in the properties of the low-carbon alloys, particularly as regards ductility. An investigation has therefore been carried out to determine the influence of hydrogen on the mechanical properties of such alloys and also on commercial Hadfield manganese steel.

The low-carbon alloys were made in a basic lined induction furnace using electrolytic manganese and hydrogen-free electrolytic iron and cast into steel moulds, excepting 10 B, which was sand cast, without the addition of silicon or other deoxidisers. The 1 in. diameter ingots were homogeneised at 1050° C. for 1 to 2 hours, swaged to slightly over ¼ in. diameter, annealed in air at 1050° C. for one hour, then machined. The composition of the iron alloys tested together with those of two commercial Hadfield manganese steels, and electrolytic iron are given in Table I. Test specimens, 0·16 in. diameter, 0·8 in. gauge length were heat-treated in quartz tubes either continually evacuated or containing slowly flowing purified hydrogen. Such specimens were either heated in hydrogen at 1000° C. for 2 hours and cooled or given the same treatment followed by heating at 1000° C. or 550° C. for one hour in vacuum and similarly cooled. The effect of such treatments on the tensile strengths, elongation, reduction of area and other properties were then determined.

TABLE I.—COMPOSITION OF MANGANESE IRON ALLOYS.

Specimen	Manganese %	Carbon %	Nickel %
Electrolytic-iron	0·0	0·005	—
Alloy 3	3·3	0·02	—
„ 6	6·3	0·02	—
„ 7	7·4	0·02	—
„ 10A	9·9	0·02	—
„ 10B	10·3	0·02	—
„ 12	11·6	0·02	—
„ 14	14·0	0·02	—
„ 18	17·6	0·02	—
„ 22	21·5	0·02	—
COMMERCIAL HADFIELD MANGANESE STEEL.			
Alloy A	13·4	0·75	3·0
„ B	13·7	1·34	Nil

From the data obtained, it was found that low-carbon manganese-iron alloys, containing 9 to 22% manganese, hydrogen-treated at 1000° C. and quenched are embrittled by retained hydrogen and this applies to both large and small test specimens (0·505 and 0·160 in. diameter). Small size specimens, however, of electrolytic iron and a 3·3% manganese-iron alloy were not embrittled, due to the hydrogen dissolved at 1000° C. not being retained, no matter how rapid the quench. Alloys vacuum-treated at 1000° C. and quenched in vacuum lose hydrogen and are ductile, with the exception of alloys containing 6 to 7% manganese. The latter are brittle because of the formation on quenching of a metastable alpha phase which is also evident in the 3·3 and 10% manganese alloys. The 21·5% manganese-iron alloy is less ductile than the expected value by extrapolation because with cold-work it practically completely transforms to a brittle phase. Tempering at 550° C. transforms the metastable or supersaturated alpha to equilibrium alpha phase and improves the ductility of the alloys, particularly those containing 3 to 10% manganese. Any significant effect of tempering to improve the ductility of alloys containing 12 to 22% manganese is by removal of hydrogen.

The reduction of area and elongation of alloys containing 3·3, 6·3 and 7·4% manganese, vacuum-treated and hence low in hydrogen are dependent on the rate of cooling. A rapid water quench instead of a slower quench in vacuum decreases the ductility of 3·3% manganese but increases the ductility of 6 to 7% manganese-iron alloys and has no significant effect on the properties of the higher manganese compositions. The loss of hydrogen manifested by the gain in the ductility of the 14% manganese-iron alloy on heating in

From *Metals Technology*. 1944, vol. 11, No. 4, A.I.M.M.E. Technical Publication No. 1701, 19 pages.

hydrogen or vacuum for one hour at various temperatures is explained on the basis of high diffusion rate of hydrogen in the alpha phase and the high solubility of hydrogen in the gamma phase.

Appreciable hydrogen is retained by the high carbon 14% manganese-iron alloy (Hadfield manganese steel) on quenching from 1000° C., but has no effect on the tensile and impact properties in contrast to results obtained with the low-carbon 14% manganese-iron alloy. Exposure to cathodic hydrogen in a sulphuric acid electrolyte embrittles alloys containing 10 to 14% manganese, but has no effect on other alloys of the series including commercial Hadfield manganese steel, due to lack of sufficient hydrogen absorption by such alloys.

Lubrication for Blast Furnaces

By A. J. Jennings

A CENTRALISED lubricating system for blast-furnaces is advantageous because it delivers the lubricant under pressure to every bearing from one stage central point, each bearing getting the proper amount of lubricant. This system not only keeps men out of the danger zone by providing complete lubrication from the hoist room, but it also eliminates one of the principal sources of gas leakage by giving proper lubrication to the packing seal on the distributor ring. Clean lubricant is served to all bearings through a closed system of piping, starting with the barrel transfer pump and ending with the final bearing convection. The drum may be covered with dirt, but fresh lubricant is still delivered to the bearings on the furnace top without any chance of contamination.

Signal lights between two pumping units are operated by a pressure control valve on the top beyond the last lubricant measuring valve. The control valve ensures that, even on the coldest day, sufficient pressure is developed to overcome the resistance in the supply lines and to operate every lubricating valve before the signal light will operate. All main header piping should be accompanied by a separately wrapped steam tracer line, and all bundled together and covered by a protective jacket of insulating material. Header piping should be at least 1½ in. (32 mm.) and preferably 1½ in. (38 mm.). Otherwise it is impossible to move the lubricant on very cold days. Installations of manually-operated systems have been made on stock-house line-shaft bearings that operate the feed bins. This makes a good application, for there are about 250 2 in. × 5 in. (5 cm. × 12½ cm.) sleeve-type bearings to be lubricated each 8 hours. This is accomplished in 5 mins., with each bearing getting a measured charge.

A 400 lb. (180 kg.) drum of grease is connected to a central pumping unit and will last six months. With the old hand method each bearing was visited three times a day. As a result of giving all bearings regular attention, centralised systems do a good job, ensure production, preserve equipment, save critical materials, and provide safety for the oiler.

[From *Iron and Steel Engineering*, May, 1944.

Two Ladle Inoculation Alloys for Improving Cast Iron

TWO ladle inoculation alloys are being produced by the Electro Metallurgical Co., unit of Union Carbide and Carbon Corporation, New York City, for the improvement of cast iron. "SMZ" alloy contains silicon, manganese, zirconium and iron. It produces a strong graphitising effect and provides an economical and efficient means of obtaining a machinable high-strength grey iron from a low-silicon white iron; producing an improved grey cast iron by a ladle addition; reducing chilling at the edges, corners, and thin sections of castings without sacrificing mechanical properties in the heavier sections; and reducing wall sensitivity of cast iron. "SM" ferro-chrome alloy is used for making chromium additions to iron or steel in the ladle. This alloy is made in two grades—a high-carbon grade containing 60 to 65% chromium, and 4 to 6% each of silicon, manganese and carbon; and a low-carbon grade, containing 62 to 66% chromium, 4 to 6% each of silicon and manganese, and a maximum of 1·25% carbon.

From *Machinery*, August, 1944.

Roasting Mixed Copper Ores

By C. C. Downie

ORES containing a small proportion of iron and copper pyrites can either be smelted for the concentration of matte or alternately roasted in preparation for wet extraction. Attempts have been made to wash out the sulphide copper content by leaching, but copper did not appear to be sufficiently soluble unless a large excess of acid was used. A different state of affairs exists where sulphide can be roasted to a soluble condition, since solubility may be attained without addition of acid. There is no point in roasting the carbonate copper ores, as is done with calamite or other zinc carbonate ores, since solubility is not improved.

When pyrites are heated around 502° F. (261° C.) part of the sulphur is evolved and sulphate of iron formed is converted into $Fe_2(SO_4)_3$. On raising temperature to 986° F. (530° C.) practically the whole compound is converted to ferric oxide. With copper present, sulphate formation begins at 698° F. (370° C.) and this continues rapidly at 1,112° F. (600° C.), but at about 1,407° F. (764° C.) copper sulphate is converted to 2 $CuO.SO_3$, which at 1,299·2° F. (704° C.) forms CuO. The intermediate oxide, Cu_2O is undesirable, since when decomposed by H_2SO_4 it is partly resolved into CuO and metallic copper. Although CuO dissolves in acid, the finely divided copper is in condition for precipitation and it is here that it is so detrimental where silver is also present in the ore. Therefore, efforts are made to control the roasting so as to produce CuO alone, and when Cu_2O is revealed the material is returned for further roasting so that more oxygen is absorbed.

By means of judicious mixing of the material, it is possible to render the whole of the contained copper into soluble condition, whereby, instead of roasting being limited to ores with a small proportion of pyrites or sulphides, those containing carbonates and

From *Mining Magazine*, May, 1944.

hydrates can be incorporated. Fuel costs are of primary importance where only a small amount of copper exists. Grinding is also of great importance. The material should pass through a 32-mesh sieve, but it is also desirable to remove the finer particles. For the roasting a muffle furnace is preferred to mechanically operated roasting hearth. One advantage is that in the muffle CO is absent, this being one of the worst agents for converting freshly formed copper sulphate into CuO. Precipitated copper, whether impurities are incorporated or otherwise, is conveniently dealt with by an improved system of applying electrolytic refining, as the soft red mass is compressed to anodes instead of the circuitous drying and melting system.

Retorts for Magnesium Distillation

By F. B. Foley and R. L. Sebastian

IN the Pidgeon process, briquets of dolomite and ferrosilicon are heated within metal retorts to 2·150° F. (1·180° C.) under a pressure of 0·1 mm. mercury. Retorts are cylindrical castings, 8 to 10 ft. (2·40 to 3 m.) long, 10 in. (25 cm.) inside diam., with about 1 in. (25 mm.) wall thickness, closed at one end by welding on a hemispherical dome, and on the other end by welding on a water-cooled wrought-steel chamber, in which the magnesium vapour condenses. The process is a discontinuous one, involving 8-hr. cycles, which include 2 hours for charging, discharging, and cleaning out. The temperature, however, is maintained steadily throughout the cycle. A wall thickness of $\frac{7}{8}$ in. (22 mm.) was decided upon. Alloys tried for retorts were 35 Ni and 15% Cr; 25 Cr and 12% Ni; and 28 Cr and 20% Ni. In addition, experiments were carried on with plain steel tubing coated by welding a layer of 25 Cr and 20% Ni alloy over the surface to prevent oxidation.

None of these alloy retorts is capable of withstanding a pressure of about one atmosphere at 2,150° F. (1,180° C.). All flow at a fairly rapid rate, leading to intolerable collapse of the retorts in a short time. It was decided to adopt an alloy containing 28 Cr and 15% Ni, as this is adequate in resistance to the oxidising conditions at 2,150° F. (1,180° C.).

Increased life is possible only by resorting to mechanical means, such as increasing the wall thickness, using reinforcements, and, most effectively, by expanding each time excessive collapse occurs.

Collapsed retorts can be reclaimed by blowing them out virtually to shape by means of 90 lb./sq. in. (6·3 kg./cm.^{2}) air pressure, introduced into the retort while sealed and at operating temperature, for two or more hours. Two retorts had their lives extended to a year by repeated expansions.

The high-chromium alloys have higher average total life than the high-nickel alloy. A somewhat longer average life appears to result from static casting of $1\frac{1}{2}$ in. (28 mm.) wall retorts than from centrifugal casting.

From *Alloys*, June, 1944.

Radiography of Non-Uniform Sections

By R. Taylor.

THE one disadvantage in the use of gamma-rays for radiography has been the necessarily excessive length of exposures, particularly in radiographing complicated castings of non-uniform sections in which each individual section is exposed separately. A method, applicable to castings of complicated shape wherein the range of thickness, over which inspection must be effective, might vary to a considerable extent, has recently been developed, and involves a single exposure technique using two suitable chosen films in one holder.

The double film method for radiographing of castings of complicated shape was carried out as follows: If a casting was an aluminium or magnesium base alloy, Kodak type A film was placed nearest the tube and Kodak Type K film furthest from the tube and one exposure made to cover the various ranges of thickness of the casting, lead screens being eliminated in the radiography of light alloys. If the casting was of steel or brass and and non-uniform in range of thickness, a front lead foil screen of 0·005 in. was placed in an exposure holder after which a Type A film was placed, followed by another 0·005 in. of lead foil and a Type K film backed up with lead foil 0·015 in. thick. A single exposure reveals two films, one for each range of thickness with sensitivity satisfactory to detect a void within 2% of the thickness of any section.

Exposure graphs show that a Type K film will record a thickness range of steel of from 3 in. to 5·5 in., whereas Type A film will record, at the same exposure factor, a thickness range from 1·2 in. to 3·4 in. Combining both films for a steel casting whose range of thickness varies from 1·5 in. to 5·5 in. over its entire range gives a satisfactory sensitivity in executing a single exposure of the entire casting instead of making two exposures.

In preparing the exposure holders for gamma-ray radiography by the single exposure method, three lead screens 0·015, 0·015 and and 0·030 in. thick respectively are placed in a single exposure holder, the films A in front and K in back being inserted between the lead sheets.

From *Metals and Alloys*, 1944, vol. 19, No. 6, pp. 1393–1395.

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "Metallurgia" should not be taken as an indication that they are necessarily available for export.

SUPERINTENDENT required for Works Laboratories in S.W. England. Age 35-40. Wide experience in the analysis of metallurgical and chemical products required; some knowledge of spectrographic analysis of metals desirable, although not essential. Applicants should preferably have been in charge of a laboratory, and must possess qualities of administration and leadership, together with B.Sc. or equivalent qualification. Gross salary offered in the region of £550 per annum. Post permanent. Applicants should write quoting F.3081 x A to the Ministry of Labour and National Sevice, Central (T. and S.) Register, Room 5/17, Sardinia Street, Kingsway, London, W.C.2, for the necessary forms, which should be returned completed on or before 30th December, 1944.